

# PHYTOLITH ANALYSIS AT WANUSKEWIN HERITAGE PARK

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By

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## ABSTRACT

Over the past 40 years, archaeological investigations at Wanuskewin Heritage Park (WHP) have revealed an unusually high concentration of archaeological sites dated to the Middle Precontact period (6000-2000 BP). Despite extensive documentation and discussion of past human lifeways within the park, to date it remains unclear why WHP was such a favoured locale. It has been suggested the valley encompassed by the park may have served as an ecological island drawing groups in from the surrounding area. Phytoliths represent an opportunity to study the presence and composition of past vegetation, particularly grasses, in order to make inferences on past climatic conditions.

The main objective of this thesis is to present a preliminary paleoenvironmental record of WHP based on the analysis of grass short-cell phytolith data from six archaeological sites within the park. This research focused on grass short-cell phytoliths as this type of analysis is particularly useful on the Northern Plains, which is dominated by a grassland environment. The phytolith morphological data was supplemented by the analysis of stable carbon isotopes from carbon occluded within phytoliths. The analysis of  $\delta^{13}\text{C}$  values supplemented the grass short-cell morphological data and included information on the entire phytolith assemblage which likely included deciduous trees and shrubs, as well as grass taxa. The analysis of  $\delta^{13}\text{C}$  values and radiocarbon dates from phytoliths are relatively new procedures. This research project presented an opportunity to test the accuracy of radiocarbon dates obtained from phytoliths. The final objective of this thesis is to place the local paleoenvironmental data from WHP within the broader paleoenvironmental context of the Northern Plains. The data collected here suggest that overall, the post-5000 BP environmental record at WHP fits well with data collected elsewhere in Saskatchewan.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

Human responses to changing Holocene climates on the Northern Plains are a subject of great interest. Despite the importance of this research, little data have been produced to empirically address the topic. Wanuskewin Heritage Park (WHP), located 12 km northeast of the city centre of Saskatoon, SK (Figure 1.1), is a prime location to study this topic. WHP has an unusually high concentration of archaeological sites dated to the Middle Precontact period (6000-2000 BP) (Walker 1988), though exactly why it was such a favoured locale has yet to be confirmed. Previous research within the park has focused on the investigation of the archaeological remains to advance our understanding of past human use of the Opimihaw Creek Valley (e.g. Pletz 2010; Smith 2012; Webster 1999), which is encompassed by the park boundary. What is missing from this research is a developed paleoenvironmental record for the valley (e.g. Pletz 2010; Smith 2012; Stead 2013).

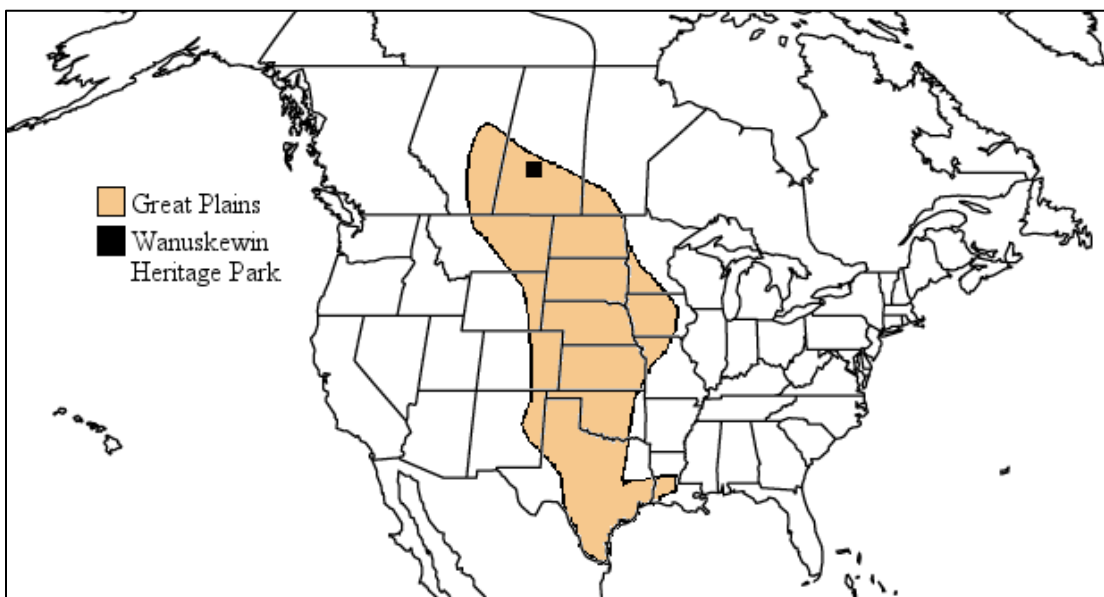


Figure 1.1: Map showing the location of Wanuskewin Heritage Park within the Northern Plains.



Archaeological excavations at WHP over the past thirty years have yielded an extensive collection of lithic and faunal resources, as well as a few plant macroremains. These collections have allowed for the documentation and discussion of past human lifeways within WHP, including but not limited to diet, butchering practices, and lithic technologies employed during the Middle and Late Precontact periods (e.g. Cyr 2006; Johnston 2005; Webster 1999). This research has indicated the valley was an important habitation centre, as evidenced by the multi-component and multi-occupational nature of nearly every archaeological site within the park (Walker 1988). The area is clearly well suited for bison procurement as evidenced by the presence of multiple bison kill and butchering sites within the park (Walker 1988).

It seems likely that paleoenvironmental factors played an important part in drawing people to the valley (Pletz 2010; Smith 2012; Stead 2013). Currently, the closest “local” paleoenvironmental records come from lake cores from regions in the south of the province or from neighbouring Alberta and North Dakota (e.g. Valero-Garcés et al. 1997; Vance et al. 1995). These regional records are useful but lack the specificity required to explain the role environment may have played in producing the settlement patterns we see at WHP. A local record of environmental change for WHP is required to obtain a dataset which can be compared to regional records to aid in understanding how past peoples may have responded to climate change within the local area. Aligning the paleoenvironmental record for the park with the archaeological record will provide the potential to interpret cultural adaptations that may or may not be related to periods of Holocene climate change. Calls for this have begun to be answered. Research by Stead (2013) began to develop a paleoenvironmental record for WHP and continuing research by Stuart (e.g. Stuart & Walker 2016) seeks to build a local palynological record for WHP.

Stead (2013) analyzed sediments from the Red Tail Site (FbNp-10). Stead’s study was successful in achieving her research goals of identifying phytolith analysis as a successful method for paleoenvironmental research at WHP and beginning to develop a paleoenvironmental context for archaeological research within the park. Building upon her research, the current study involves the analysis of grass short-cell phytolith data from six other previously excavated archaeological sites within WHP in order to offer a broader interpretation of the paleoenvironment of the valley. The sites chosen for analysis in this study include: Dog Child

(FbNp-24), Thundercloud (FbNp-25), Wolf Willow (FbNp-26), Amisk (FbNp-17), Cut Arm (FbNp-22), and Tipperary Creek (FbNp-1) (Figure 1.2).

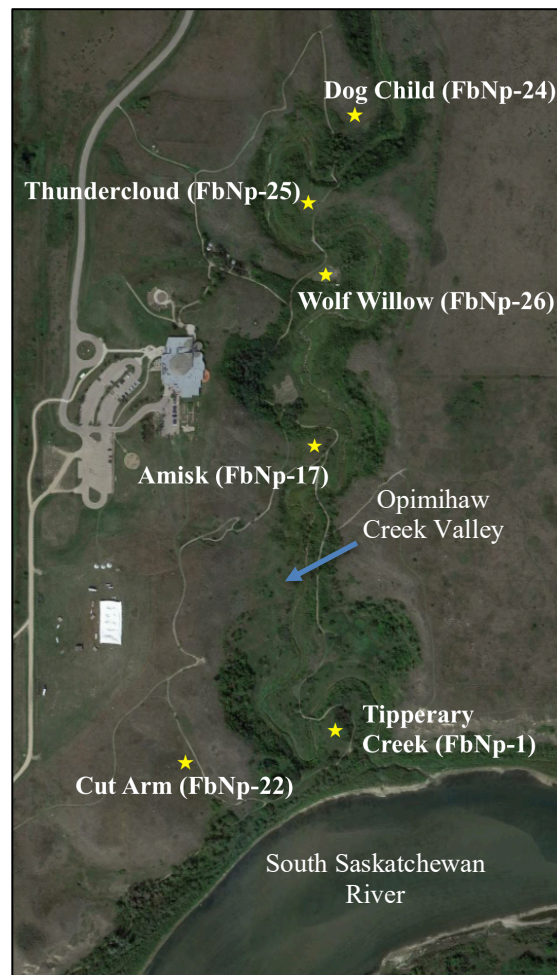


Figure 1.2: Map showing the location of the archaeological sites examined in this study (GoogleEarth2016, modified by author).

Phytoliths represent an opportunity to study past vegetation in order to make inferences on past climate conditions. In this research the analysis will focus on grass short-cell phytoliths as the analysis of these phytoliths is particularly useful in interpreting past climate conditions on the Northern Plains (e.g. Fisher et al. 1995; Fredlund & Tieszen 1994, 1997). To supplement the proxy data gained through phytolith analysis, stable carbon isotope data from carbon occluded within phytoliths in the form of  $\delta^{13}\text{C}$  values and radiocarbon dates is also presented. The  $\delta^{13}\text{C}$  values will provide information on the relative amounts of phytolith-forming  $\text{C}_3$  and  $\text{C}_4$  plants, which may include grasses, shrubs, and trees. The analysis of radiocarbon dates obtained from phytoliths will serve to test the accuracy of radiocarbon dates using the phytolith extraction

method employed in this research. Currently, the literature regarding radiocarbon dates from phytoliths suggests results are inconsistent when compared to existing radiocarbon dates from other organic materials (e.g. Piperno 2016; Santos et al. 2010). WHP represents an opportunity to test the accuracy of radiocarbon dates obtained from phytoliths, as several radiocarbon dates from sites within the park already exist and these dates can be correlated with the associated date ranges of projectile point styles recovered from individual sites. The analysis of carbon isotopes (both  $\delta^{13}\text{C}$  values and radiocarbon dates) from phytoliths is a relatively new procedure, thus this thesis will employ a new technique to add to the growing body of work exploring the utility of phytoliths in paleoenvironmental reconstructions. Analysis of samples for radiocarbon dates and  $\delta^{13}\text{C}$  values will enhance and refine the paleoenvironmental interpretation from phytolith morphology alone.

## **1.2 Research Objectives**

The main objective of this thesis is to continue to develop a paleoenvironmental record for WHP. This will improve our understanding of how the environment of the park fits within the broader environmental context of the Northern Plains. Local and regional paleoenvironmental records are paramount in interpreting local responses to environmental change. A local record of environmental change for WHP is required to aid in the understanding of if, or how, past peoples responded to climate change within the immediate area. The objectives of this thesis (as outlined below) are to relate the paleoenvironmental record at WHP to the broader environmental framework of the Northern Plains. To summarize, this research seeks:

- 1) To continue to develop a local record of paleoenvironmental change within Wanuskewin Heritage Park through the analysis of phytolith morphological data.
- 2) To obtain  $\delta^{13}\text{C}$  values from phytoliths to supplement the data obtained from grass short-cell phytolith morphological data alone.
- 3) To test the accuracy of radiocarbon dates obtained from phytoliths using the extraction method employed in this research.
- 4) To discuss how the local paleoenvironmental data derived from the phytolith analyses fit within the existing Holocene environmental record of the Northern Plains.

### **1.3 Organizational Summary**

The content of this thesis is organized into eight chapters, including this introductory chapter. Chapter 2 will outline the biophysical background of the Opimihaw Creek Valley which is encompassed by WHP. It will also include a review of the current climate and ecology as well as a discussion of the natural and cultural stratigraphy of the archaeological sites involved in this study. Chapter 3 provides background on phytolith analysis and documents their utility as a paleoenvironmental proxy on the Northern Plains. Chapter 4 provides a summary of Holocene environmental change and a summary of human-environment interaction on the Northern Plains. Chapter 5 outlines the use of stable carbon isotopes as they relate to phytoliths and provides a discussion on how they can supplement data obtained from phytolith morphological analysis alone. Chapter 6 explains the field, laboratory, and analytical methods used in this thesis. In Chapter 7, the results are presented and interpreted in relation to the paleoenvironment of WHP and in relation to the broader environmental framework of the Northern Plains. Chapter 8 summarizes the research and interpretations of this thesis and discusses conclusions reached as a result of this research. Chapter 8 will also outline areas of future research that may build on the results of this thesis.

## CHAPTER 2

### BIOPHYSICAL BACKGROUND

#### **2.1 Introduction**

Wanuskewin Heritage Park (WHP) is located 12 km northeast of the city centre of Saskatoon, SK in the SE1/4 of Section 35 and the SW1/4 of Section 36, Township 36, Range 5, West of the 3rd Meridian. The park encompasses the Opimihaw Creek Valley, a tributary of the South Saskatchewan River, as well as the surrounding uplands and a small portion of the South Saskatchewan River valley (Figure 1.2). The purpose of this chapter is to describe the biophysical background of the study area including a brief summary of the glacial history of the Opimihaw Creek Valley and the post-glacial processes that contributed to the current characteristics of the valley. A discussion of the natural and cultural stratigraphy of the archaeological sites involved in this study is included to understand the depositional environment of the samples examined. A description of the current climate, soils, and flora is also included to outline the current environmental conditions of the area.

#### **2.2 Geomorphic History of the Opimihaw Creek Valley**

The Opimihaw Creek Valley is located within a former channel braid of the South Saskatchewan River (Christiansen & Sauer 1998; Figure 2.1). The stream flow of the Opimihaw Creek originates at the Hudson's Bay slough northeast of the study area and flows in a southwest direction into the western bank of the South Saskatchewan River. Glacial and glacio-lacustrine processes controlled the geologic history of the region prior to 8000 BP, while colluvial and alluvial processes dominated the geomorphology of the Opimihaw Creek Valley throughout the remainder of the Holocene.

##### **2.2.1 Glacial History**

The Saskatoon region experienced several glaciation events, but this discussion will focus on the effects of the final Wisconsin Glaciation on the geomorphology of the study region. At the height of the last glacial maximum, at approximately 18 000 BP, the Wisconsin Glacier extended

south into Montana and South Dakota (Colgan et al. 2003). North of Saskatoon the soft, massive, brown and grey tills of the Battleford Formation make up the glacial deposits from this final glaciation event (Figure 2.1) (Christiansen & Sauer 1998). The Battleford Formation underlies the Holocene surficial deposits that have accumulated in the Saskatoon region over the past 10 000 years (Burt 1997). The contact between the upper boundary of the Battleford Formation and the Holocene surficial deposits is conformable and represents a gradation from glacial melt-out till to glacio-lacustrine deposits (Christiansen 1992; Christiansen & Sauer 1998). Holocene surficial deposits that overlay the Battleford Formation are composed of sand, silts, and clays of deglacial lacustrine, outwash and ice-contact sediments, and postglacial alluvium, colluvium, aeolian, and landslide deposits (Christiansen 1992:1776). The surficial deposits of the Saskatoon area just 5 km south of the current study area are made up of the Grasswood Allomember of the Haultain Formation (Figure 2.1). The Grasswood Allomember is composed of glaciolacustrine silt and clay deposited by Glacial Lake Saskatchewan (Christiansen & Sauer 1998).

Christiansen (1979) developed a nine-phase model of the deglaciation of southern Saskatchewan, which is generally accepted by most scholars (Burt 1997). Phase 6 of Christiansen's glacial retreat shows that by 12 000 BP the glacial ice margin had retreated to just north of the Saskatoon area. Glacial meltwater from this retreat, along with meltwater from the Rocky Mountains (via the North and South Saskatchewan Rivers), poured into Glacial Lake Saskatchewan, which grew to inundate what is now the Saskatoon area. Meltwater drainage via the North Saskatchewan River into Glacial Lake Saskatchewan formed an unnamed delta on the northwest margin of the lake, consisting of fine-grained lacustrine silts and clays (Christiansen 1979). By phase 7 the boundary of glacial ice and Glacial Lake Saskatchewan moved northward to the Prince Albert area 75 km north of Saskatoon, leaving the Saskatoon area both ice- and water-free by 11 500 BP (Figure 2.2) (Christiansen 1979). The northward drainage of Glacial Lake Saskatchewan was facilitated by the highly braided channel system of the South Saskatchewan River (including the channel that now encompasses the Opimihaw Creek), the Hudson Bay Channel, and the Grass Lake Channel (Figure 2.1) (Christiansen & Sauer 1998).

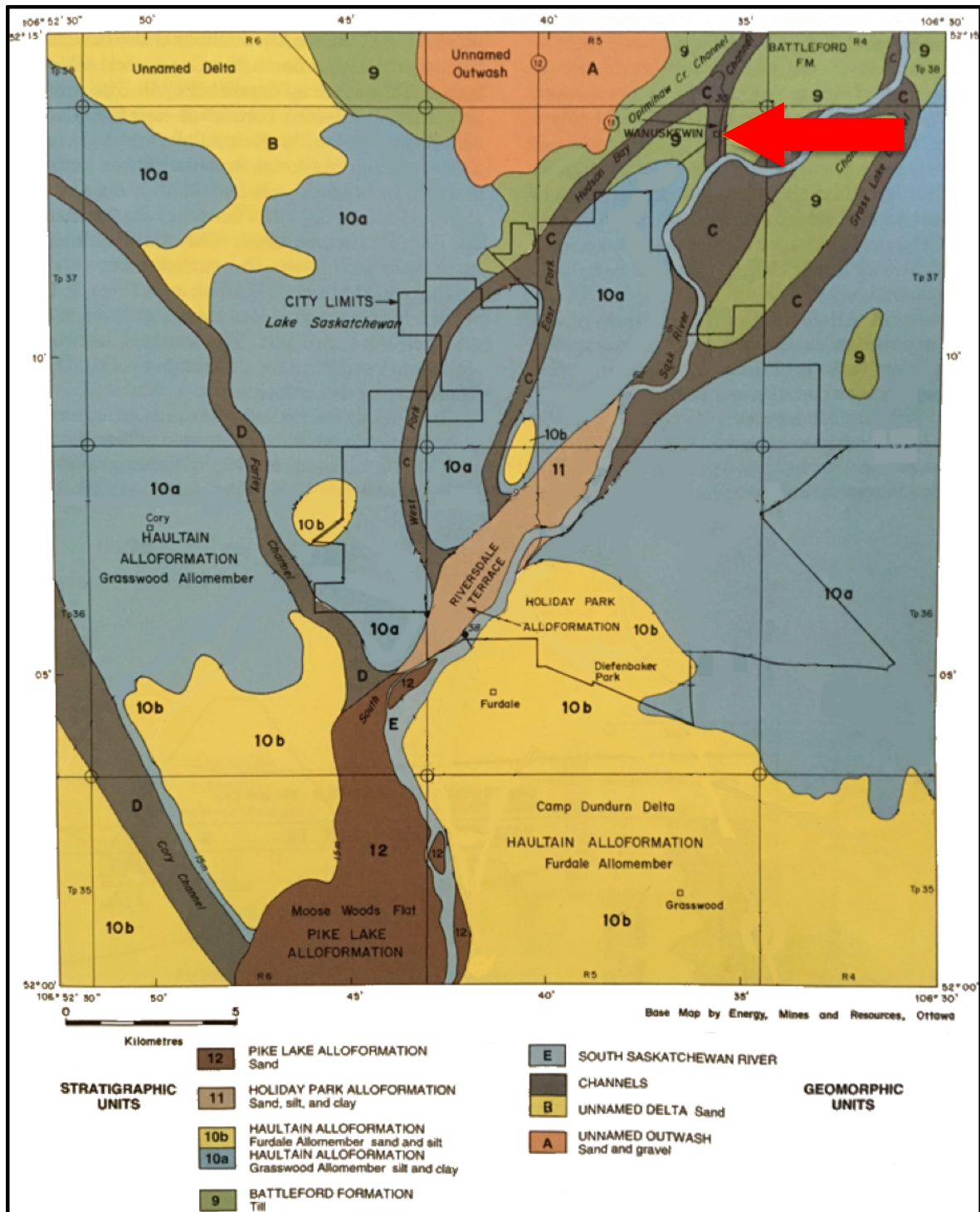


Figure 2.1: Surficial geology of the Saskatoon area after Christiansen and Sauer (1998:125). Note the arrow marking the approximate location of Wanuskewin Heritage Park within a former braid channel of the South Saskatchewan River.



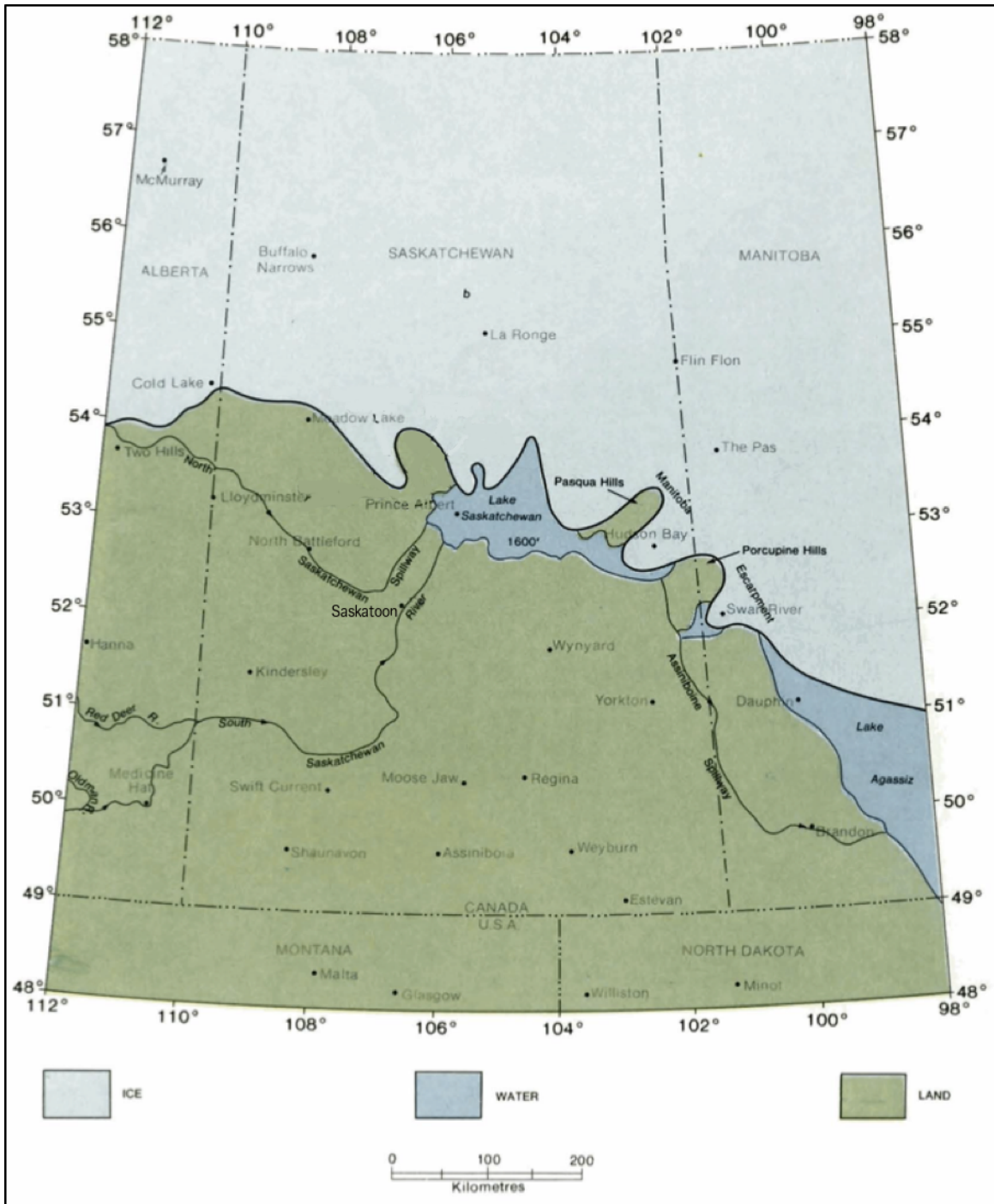


Figure 2.2: Phase 7 of the deglaciation of Saskatchewan, approximately 11 500 BP after Christiansen (1979:929).



### **2.2.2 Post-Glacial Development of the Opimihaw Creek Valley**

Based on Christiansen's deglaciation model the maximum age of the Opimihaw Creek Valley is 11 500 years, although some scholars suggest 10 500 years as a more likely date for complete deglaciation and drainage of the Saskatoon area; for a full discussion see Burt (1997:30-33). The post-glacial development of the Opimihaw Creek Valley, as described by Burt (1997), involves three phases: post-glacial, aggradation, and modern creek development. These phases are summarized here.

The flow of glacial meltwater and aquifer discharge into the South Saskatchewan River combined with the cool, moist climate of the early post-glacial period facilitated incision of the valley (Burt 1997:168). Burt (1997:167-169) suggests a sinuous or meandering stream existed in the valley as early as 10 500 BP (Figure 2.1) with sufficient energy to down-cut the valley and cause undercutting and slumping of the valley walls. At this time the South Saskatchewan River, which serves as the base level for the Opimihaw Creek, was also down-cutting in response to a drop in its own base level caused by the breaching of Glacial Lake Agassiz (Burt 1997:165).

Incision of the South Saskatchewan River valley must have taken place prior to 8100 BP as evidenced by paleosol development on the Saskatoon Terrace at this time (Burt 1997:171). Gullies, terraces, and meander scars within the Opimihaw Creek Valley serve as remnants of this erosional phase of valley development (Burt 1997:169-170). The incision phase lasted into the warm, dry period known as the Hypsithermal (ca. 8000-6000 BP) when a reduction in available moisture reduced the flow of the waters of the Opimihaw Creek (Rutherford 2004). An exact date for the end of the incision phase has not been calculated, however, ages of 4600 BP and 5000 BP, based on alluvial deposits from Newo Asiniak (FbNp-16) and radiocarbon dates from the Red Tail (FbNp-10) sites respectively, serve as maximum ages for the end of the phase (Burt 1997:172).

The aggradation phase began sometime before 4600 BP with the onset of moister climate conditions marking the end of the Hypsithermal. Scarce vegetation cover and dry surface conditions coupled with an increase in available moisture increased the sediment load of the Opimihaw Creek. According to Burt (1997), the dominant processes active during this phase were the development of depositional alluvial terraces and lateral migration of the streambed. This resulted in the lateral aggradation of point bars and the undercutting of existing valley features such as terraces and hillslopes (Burt 1997; Rutherford 2004). As climatic conditions

stabilized, so too did stream discharge and surficial sediments, due to increased vegetation cover. By approximately 4000 BP sedimentation rates within the valley decreased and conditions favourable to soil development existed (Burt 1997).

Hillslope processes, including aeolian erosion, erosion due to flowing water, and mass movement (the downslope movement of rock, sediment, and soil in response to gravity), were very active during the aggradation phase. Rutherford (2004:93) showed that hillslope processes caused by aeolian erosion and flowing water were active in the valley prior to 5420 BP. The period from 4500 BP to 3500 BP was marked with evidence of frequent hillslope processes intermittent with weakly developed paleosols. This period also marked a transition to rotational slides, a type of mass movement process, as the dominant hillslope process in the valley, rather than erosion. This shift coincides with the change from dry Hypsithermal conditions to an increased moisture regime.

Approximately 200 BP the stream returned to incising its floodplain. Based on the steeper gradient of the modern floodplain in comparison to alluvial terraces, the stream is still incising its valley (Burt 1997:180). There is no evidence to support a change in base level of the South Saskatchewan River, however, there is evidence that the river did, in fact, incise its own floodplain.

### **2.3 Site Stratigraphy**

Most archaeological sites within Wanuskewin Heritage Park are located on alluvial terraces or point bars while some lie on slopes of the valley walls and on the surrounding uplands. Of the sites examined in this study, Dog Child (FbNp-24) and Thundercloud (FbNp-25) are located on alluvial terraces, Wolf Willow (FbNp-26) and Tipperary Creek (FbNp-1) are located on point bars, Cut Arm (FbNp-22) is located on the uplands, and Amisk (FbNp-17) is located on the western slope of the valley wall (Figure 1.2). The depositional histories of these locations have a direct influence on the vegetative and cultural histories of these sites.

Burt (1997) undertook a physiographic analysis of WHP and outlined several sedimentary facies observable within the stratigraphy of the valley bottom sites. Burt's descriptions of the sites are used in this study where applicable. The Wolf Willow and Cut Arm sites were not included in Burt's analysis as the landforms associated with these sites were out of the scope of her thesis. In the present study, no attempt was made to correlate the stratigraphy at

Wolf Willow or Cut Arm with Burt's facies identifications. Radiocarbon dates are presented as radiocarbon years before present (BP), unless specified otherwise.

### **2.3.1 Dog Child (FbNp-24)**

The Dog Child site is located on a terrace and is the northernmost archaeological site within WHP (Figure 1.2). Site stratigraphy is complex as both alluvial and colluvial deposits are present on the terrace, which slopes to the east terminating in a steep bank dropping down to Opimihaw Creek. The terrace drops 10 m in elevation from west to east over approximately 100 m, which adds to the complexity of the stratigraphy. Burt (1997:134-137) took two sediment core samples, one from the base of the colluvial slope on the western edge of the site (core 9) and one from a meander scar on the southeast corner of the terrace (core 10).

Core 9 revealed a colluvial history with a base unit from 34-100 cm below surface (cmbs) assigned to facies 2B, a slightly gravelly sandy mud to slightly gravelly muddy sand low in organic carbon, indicating floodplain deposition close to the stream channel. Facies 3, which lies at 27-34 cmbs, is a gravelly muddy sand low in organic matter, likely the result of a slopewash or mass wasting event. The topmost unit, 0-27 cmbs, was classified as facies 2A, a slightly gravelly muddy sand or sandy mud high in organic matter. A significant colour change from olive brown to very dark greyish brown-black was noted in this unit. Burt notes this uppermost unit was likely stable for some time, allowing for pedogenesis. Burt also notes the soil may be cumulic, suggesting very slow sedimentation rates and long periods of stability (Burt 1997:135).

Core 10 reveals a different history, with the lowermost unit from 81-92 cmbs assigned to facies 5, a muddy sand or sandy mud matrix-supported gravel indicative of channel lag deposits, thus marking the former location of the stream channel. The overlying unit ranges from 12-81 cmbs and was identified as facies 2B. This is a highly variable unit in terms of texture and grain size ranging from slightly gravelly sandy mud to slightly gravelly muddy sand with alternating pulses of coarse sand and fine mud. Burt (1997:135-136) attributes this variability to either lateral migration of the stream channel or to changes in sediment load or discharge of the stream.

Archaeological investigations at Dog Child reveal a slightly different profile from Burt's identifications. The base of the archaeological excavations revealed a layer of large cobbles that were interpreted as representing the old stream bed (Pletz 2010:69). From 40-77 cmbs Cyr (2006:30) and Pletz (2010:68) noted the presence of two distinct gravel lenses of sand with coarse pebbles and cobbles separated by a stratum of clay ranging between 2-10 cm in thickness.

The lower gravel lens also has a weak paleosol immediately below that is not associated with cultural materials. Cultural level 3b, in some places, appears to encompass this gravel layer (Pletz 2010:68). The upper gravel lens has a weak paleosol immediately below which is associated with materials from cultural level 3a. It is possible these gravel lenses are related to Burt's facies 5 present in core 10, however, the datasets are difficult to compare given the slope of the terrace.

From 0 cm to approximately 40 cmbs Cyr (2006:29-30) and Pletz (2010:63-67) identify a series of strata that range in texture from clayey sand to coarse sand and in some strata note the presence of small pebble lenses while other strata have small pebbles and gravel mixed in. This would seem to correlate with Burt's highly variable facies 2B from core 10. The identification of four paleosols within this unit separated by bands of light coloured sands and the recovery of cultural materials from each buried soil (Cyr 2006:29-30; Pletz 2010:63-67) suggests these strata are the result of floodplain deposition in close proximity to the streambed, followed by periods of pedogenesis.

### **2.3.2 Thundercloud (FbNp-25)**

The Thundercloud site is located on an alluvial terrace in the northern part of the park (Figure 1.2). Immediately below the sod layer at approximately 5 cmbs is a thin layer of charcoal and stained earth suggested to be the result of a prairie fire (Webster 1999:29). The next stratum lies at 5-24 cmbs and corresponds to Burt's facies 2A, a slightly gravelly sandy mud to slightly gravelly muddy sand. This unit is high in organic matter and contains three paleosols associated with cultural levels 1-3. Alternating bands of black to very dark greyish brown sediments indicate these are cumulic regosols (Burt 1997:131). The sediments in this stratum are fine-grained, suggesting deposition fairly near to the creek channel and were likely deposited by periodic episodes of channel flooding punctuated by short periods of stability and pedogenesis (Webster 1999:29). Below is a thin layer of Burt's facies 3. Burt documents this unit as terminating at 24 cmbs with an undulating upper boundary ranging from 15-19 cmbs (Burt 1997:131) while Webster (1999:30) documents this unit as present from 24-28 cmbs. This unit of gravelly mud and gravelly muddy sand likely represents colluvium from a slope wash or mass movement event that originated on the slope east of the site (Burt 1997; Webster 1999:30). Directly below is a thin stratum from 24-30 cmbs of Burt's facies 2A which contains a paleosol and cultural level 4. The undulating nature of the base of this stratum suggests deposition and

pedogenesis followed by an erosional discontinuity (Burt 1997:130). A radiocarbon date of  $2570 \pm 50$  BP was obtained from this level (Webster 2004:34).

Beneath is a thin layer of Burt's facies 1B overlying a layer of facies 1A. 1A is approximately 34-37 cmbs and is represented by very fine-grained sediments with an unexpectedly low organic carbon content for a facies 1A designation (Burt 1997:129). Within this stratum lies cultural level 5 which produced radiocarbon dates of  $3150 \pm 50$  BP,  $3315 \pm 50$  BP, and  $4040 \pm 90$  BP (Webster 2004:35). As an explanation for the very fine-grained sediments, Webster (1999:30) proposed the creek had meandered away from the site, or environmental change during this period may have resulted in lower water levels in the creek. The stratum below ranges from 37-53 cmbs and represents a higher energy depositional environment as evidenced by the slightly gravelly muddy sand texture. This stratum is defined as belonging to Burt's facies 2A and has a high organic content. This stratum is interpreted as being located close to the streambed and represents episodes of floodplain deposition alternating with periods of sufficient stability for pedogenesis (Burt 1997). Cultural level 6 is located at the base of this unit.

From 50-70 cmbs is a unit of gravelly muddy sand belonging to facies 2B. The coarse sediments of this unit likely represent proximity to the streambed or possibly the location of the streambed itself (Burt 1997). A limited manifestation of cultural level 7 is present in the eastern part of the site at 75 cmbs. This material may have been disturbed and redeposited as the creek crossed the site (Webster 1999:28). This interpretation is evidenced by the classification of the sediments of this level as belonging to Burt's facies 5, a sandy matrix-supported gravel, from 80-120 cmbs. The coarse sediments of this unit are attributed to stream channel deposits, most likely channel lag, and represent lateral migration of the stream channel westward across the terrace (Burt 1997:100; Webster 1999:31).

### **2.3.3 Wolf Willow (FbNp-26)**

In general, the sediments found at Wolf Willow are typical of point bar deposition and lateral migration of the stream channel, however, the presence of two enigmatic gravel lenses have made the depositional sequence at Wolf Willow difficult to interpret. From approximately 4-25 cmbs a slightly gravelly muddy sand with a high organic matter content is present. This stratum has been identified as a cumulic A horizon and includes cultural levels 1 and 2,

suggesting a stable environment where pedogenesis was consistent with, or outpaced, deposition (Burdeyney 2015). This is typical of the uppermost stratum of a point bar sequence, as the channel migrates farther away from the point bar the surface is less likely to be overlain by flood deposits (Waters 1992:133). From 25-36 cmbs a muddy sandy gravel extends through the southern area of the site; the result of a chute bar deposit (Stumborg 2016:51) that likely formed between 2530-2230 BP (Burdeyney 2015). Cultural level 3 is found immediately below this gravel layer (Mampe 2015:86; Stumborg 2016:122).

From 36-48 cmbs is a slightly gravelly muddy sand, greyish brown in colour, which overlies a stratum of the same texture but dark greyish brown in colour from 48-52 cmbs. Cultural level 4 occurs within these gravelly muddy sand sediments at a depth of 38-59 cmbs. Spanning 52-61 cmbs is a light grey gravelly muddy sand. Extending 61-75 cmbs lies a white sandy gravel which is likely the result of channel lag deposits. These sediments represent a typical point bar sequence, consisting of channel lag deposits at the base overlain by coarse sand deposits that grade upward to fine sand or mud deposits (Waters 1992:133). At the very base of the profile from 75-81 cmbs lies slightly gravelly fine-grained sand with discrete lenses of green coloured clays invading the gravelly sand. These sediments are interpreted as representing deltaic deposits from the unnamed delta on the northwest edge of Glacial Lake Saskatchewan (Burdeyney 2015; Section 2.2.1).

#### **2.3.4 Amisk (FbNp-17)**

The Amisk site is located on a colluvial slope west of the modern stream location (Figure 1.2). The dominant site formation processes are colluvial in nature and are largely the result of slope wash and mass wasting events. The stratigraphy of the site provides no evidence of fluvial processes affecting site formation (Burt 1997:154). Below the sod layer the uppermost unit of the site is classified as facies 2A, a slightly gravelly sandy mud fining upwards to a slightly gravelly muddy sand at the top of the unit. This unit extends to 25 cmbs and contains cultural level 1. The unit below ranges from 25-43 cmbs and is assigned to facies 3, a gravelly muddy sand deposited by slope wash. The base of this unit shows evidence of pedogenesis, suggesting deposition was intermittent, with a period of stability after initial deposition (Burt 1997:154). Cultural level 2 is found within this unit at a depth of 23-40 cmbs.

From 43-70 cmbs is a unit of slightly gravelly sandy mud low in organic matter, associated with facies 2B. Under this lies a thin layer of facies 2A from 70-74 cmbs that exhibits

an undulating upper boundary, suggesting erosion (Burt 1997:153). This unit contains cultural level 3, which is associated with a paleosol (Amundson 1986:54), reflecting a period of stability. A return to Burt's facies 2B is marked from 74-80 cmbs, identified based on a decrease in organic matter. Beneath, from 80-105 cmbs, lies Burt's facies 2A, marked by an overall increase in organic matter. In this unit cultural levels 4 and 5 are associated with paleosols identified on the basis of increases in organic matter (Burt 1997:150). Cultural level 4 is associated with a cumelic regosol and cultural level 5 is suspected to be a chernozemic paleosol. Further evidence of pedogenesis in this unit is based on the undulating lower boundary coupled with colour changes (Burt 1997:151).

The lowest unit at this site ranges from 105-265 cmbs and is identified as belonging to Burt's facies 2B, a gravelly sandy mud matrix with large cobbles. Cultural level 6 was identified at a depth of 134 cmbs within an intermittent paleosol associated with large boulders (Amundson 1986:52; Walker et al. 1986:36). The base of this unit is a matrix-supported boulder layer originally identified as glacial till deposits (Amundson 1986:50; Walker et al. 1986:36). Amundson (1986:50-52) and Walker et al. (1986:36) identified the presence of a 5-25 cm thick fine loess deposit at the base of this stratum that was not present in the excavations by Burt (1997:154-155). Immediately above this stratum Walker et al. (1986:36) and Amundson (1986:52) identified a thin paleosol containing cultural level 7. A radiocarbon date of  $5340 \pm 120$  BP (Walker et al. 1986:38) was obtained from cultural level 7 at a depth of 190 cmbs (Burt 1997:151). Burt did not identify aeolian sediments in this unit and did not observe evidence of paleosol deposition. Instead, Burt suggests this unit was likely redeposited as the result of a combination of slopewash and mass movement processes (Burt 1997:151).

### **2.3.5 Cut Arm (FbNp-22)**

The Cut Arm site is located within a drainage swale on the southwestern uplands of the Opimihaw Creek Valley about 150 m north of the South Saskatchewan River (Figure 1.2). The site is situated on a prominent northwest-southeast slope resulting in a large difference between the depth of levels from the uppermost to lowermost portions of the site (Smith 2012:31). The dominant formation processes at this site are debris and overland flows punctuated by periods of stability and soil formation (Rutherford 2004:51).

The uppermost strata at this site are characterized by periods of overland flow and erosion with intermittent periods of stability and soil formation. These events are visible as dark

bands spanning from 0-35 cmbs in block 1, 0-80 cmbs in block 3, and 0-95 cmbs in block 4 (Rutherford 2004:43-50). Cultural levels 1-7 are found in association with the paleosols in these strata. Sandy gravels and gravelly sands characteristic of periodic debris flow events punctuated by periods of stability and soil formation are found from 35-57 cmbs in block 1, 80-111 cmbs in block 3, and from 95-208 cmbs in block 4. Cultural levels 8, 9, and 10 are found in these paleosols in block 4 (Rutherford 2004:43-50).

The lowermost strata on the northwest portion of the site were muddy glacial till deposits approximately 111-145 cmbs in excavation block 3. In excavation block 1 the lowermost sediments from 57-130 cmbs are slightly gravelly sands that were deposited by glaciofluvial processes (Rutherford 2004:43). On the southeast portion of the site the lowest strata at a depth of 208-231 cmbs are a mix of boulders and sand that exhibit a normally graded sequence typical of a waning debris flow (Rutherford 2004:47). Cultural level 11 is found directly above these debris flow deposits (Smith 2012:180).

### **2.3.6 Tipperary Creek Site (FbNp-1)**

The Tipperary Creek site is located on a prominent point bar at the southern extent of the Opimihaw Creek Valley where the creek drains into the South Saskatchewan River (Figure 1.2). The upper portion of this site ranges from 0 to approximately 100 cmbs and is represented by a series of thinly laminated paleosols identified by their fine-grained sand, silt, and clay texture, high organic carbon content, and dark grey to black colour (Burt 1997; Walker et al. 1987). These sediments are defined as belonging to Burt's facies 1A and likely represent repetitive periods of floodplain deposition followed by periods of stability and soil formation (Burt 1997:113-114). Thirteen cultural levels have been identified within this uppermost section with radiocarbon dates ranging from  $1535 \pm 75$  BP to  $<100$  BP (Burt 1997:112). Nearly all 13 cultural levels are associated with paleosols (Walker et al. 1987).

In the second meter below surface are sediments belonging to Burt's facies 1B, which reaches from 100 cmbs to approximately 170 cmbs (Burt 1997:113-114). These sediments are muddy sand to sandy silt and are low in organic carbon content. The presence of cultural materials in these sediments reflects floodplain deposition and proximity to the stream bed (Burt 1997:94-95). The sediments from approximately 170-230 cmbs correlate with Burt's facies 3 and 2B and are composed of gravelly muddy sands (Burt 1997:113-114). These sediments are attributed to mass movement processes or slopewash events likely originating from the slope



adjacent to the site and arising from lateral migration of the stream toward the site (Burt 1997:116). Burt (1997:116) suggests these sediments were deposited approximately 2800 BP. Cultural levels 14-18 lie in these sediments and were likely disturbed and redeposited by alluvial processes (Walker et al. 1987:38).

## **2.4 Cultural Stratigraphy**

A discussion of the cultural stratigraphy of the archaeological sites in this study is included to provide an understanding of how past peoples made use of the valley. The presence of human occupations often implies a stable land surface that may support paleosol development and vegetative growth. Human occupations can also provide age estimates of a stratum in the form of diagnostic projectile points and radiocarbon analysis of cultural materials. Radiocarbon dates are presented as radiocarbon years before present (BP), unless specified otherwise.

### **2.4.1 Dog Child (FbNp-24)**

Cultural level 1a is located immediately below the sod and is approximately 5 cm thick. Projectile points diagnostic of a Late Plains Side-notched occupation were recovered, along with pottery belonging to the Mortlach Complex and some items that infer European contact. Artifacts representative of bison processing and stone tool manufacture were found in this level, which is interpreted as a short-term campsite (Pletz 2010:90). Due to the suspected late date of occupation, no attempt to obtain radiocarbon dates was made for this level (Pletz 2010:70).

Cultural level 1b appears around 12 cmbs and is approximately 5 cm thick. Projectile points diagnostic of a Prairie Side-notched occupation were recovered, along with pottery sherds belonging to the Mortlach Complex. A radiocarbon date of  $241 \pm 50$  BP was obtained from a charcoal sample taken from a hearth feature (Cyr 2006:29). Analysis of the faunal remains suggests this may be a fall or early winter occupation, though the sample size is very small (Pletz 2010:102). A small boiling pit feature was discovered in this level but bone and lithic artifacts were sparse, implying a short-term habitation (Pletz 2010:106).

Cultural level 2a appears around 20 cmbs and is approximately 6 cm thick. Projectile points diagnostic of the McKean complex were recovered (Cyr 2006:94; Pletz 2010:111). A radiocarbon date of  $3460 \pm 45$  BP (Cyr 2006:29) suggests a Duncan/Hanna occupation (Pletz 2010:124). The overall artifact assemblage implies a winter campsite.

Cultural level 2b is approximately 6 cm thick and occurs at 23-42 cmbs, the thickness is influenced by the site's slope. Projectile points diagnostic of an Oxbow occupation were recovered. Radiocarbon dates from this level produced dates of  $3867 \pm 50$  BP (Cyr 2006:191) and  $3938 \pm 40$  BP (Pletz 2010:296). Lithic and faunal remains found in this level indicate this was a spring/summer habitation.

Cultural level 3a appears around 40-42 cmbs and is 6 cm thick. Projectile points indicative of a transitional Mummy Cave/Oxbow occupation were found (Cyr 2006:112) and are associated with two radiocarbon dates of  $4168 \pm 40$  BP (Pletz 2010:297) and  $4597 \pm 50$  BP (Cyr 2006:29). Few lithic and faunal remains were found in this level, suggesting a temporary campsite (Pletz 2010:158). Cultural level 3b occurs within the large range of 42-77 cmbs, reflecting the slope of the site. Gowen projectile points were recovered from this level along with radiocarbon dates of  $4780 \pm 50$  BP (Cyr 2006:29) and  $5003 \pm 45$  BP (Pletz 2010:298). This is the richest cultural level at the site in terms of number of artifacts and also includes a high number of faunal remains and bone tools (Pletz 2010:214). The high number of faunal remains indicates that this cultural level likely represents a long-term habitation.

Cultural level 3c is sporadically present at a depth of 70-77 cmbs, occurring in only two units at the southern edge of the excavated area. Very few faunal and lithic remains were recovered from this level but the position of the cultural materials within a darkened stratum suggests the presence of a paleosol (Pletz 2010:213).

#### **2.4.2 Thundercloud (FbNp-25)**

Cultural level 1 begins just below the sod layer and ranges from 2.5-10 cmbs. This level has multiple occupations that could not be separated stratigraphically. Projectile points diagnostic of Prairie Side-notched, Plains Triangular, and Plains Side-notched occupations, metal trade points, and Mortlach Complex pottery were recovered from this level (Webster 1999:25). Multiple hearth and boiling pit features in association with a high frequency of fragmented faunal remains suggests this occupation was a secondary processing camp (Mack 2000:98).

Cultural level 2 occurs 10-15 cmbs. As with level 1, level 2 contained multiple occupations that could not be separated stratigraphically. Projectile points diagnostic of Prairie Side-notched, Plains Triangular, Plains Side-notched, and Avonlea occupations were recovered, as was a small amount of Mortlach pottery. A high proportion of lithic debitage, faunal remains,

and multiple hearth features suggests the occupations in this level represent secondary processing activities (Mack 2000:120-121).

Cultural level 3 is present from 15-25 cmbs. This level also evidences multiple occupations that could not be separated stratigraphically. Projectile points diagnostic of Besant and Avonlea occupations and Avonlea pottery were recovered from this level (Mack 2000:148). Stone-lined pits, a hearth, and the distribution of the lithic debitage suggest this level also represents secondary processing activities.

Cultural level 4 occurs from 27-33 cmbs. A single projectile point diagnostic of a Pelican Lake occupation and one radiocarbon date of  $2570 \pm 50$  BP was obtained from this level (Webster 2004:34). Although artifacts from this level are scarce, a few lithic artifacts including stone tools and debitage were collected, along with faunal remains indicative of a spring occupation (Webster 2004:135-136). It is suspected much of the cultural material in this level was carried away by a flood event (Mack 2000:172), as evidenced by the overlying layer of gravelly mud (Webster 1999:30).

Cultural level 5 spans 33-47 cmbs. Projectile points belonging to the McKean series were found in this level. In the eastern portion of the site the cultural materials could not be separated stratigraphically, however, the western portion of this level can be broken into three separate cultural occupations: 5a is a Hanna occupation, 5b evidences Duncan, and 5c represents a McKean occupation (Webster 2004:34-35). Radiocarbon dates of  $3150 \pm 50$  BP,  $3315 \pm 50$  BP, and  $4040 \pm 90$  BP were recovered in association with levels 5a, 5b, and 5c respectively (Webster 2004:35). The remaining lithic and faunal artifacts, along with seven hearths, were difficult to separate into discrete occupations. Webster (2004:40) believes that 5a and 5b represent short-term winter and summer campsites respectively while 5c may represent secondary bison processing.

Cultural level 6 is found from 45-57 cmbs across the entire site. Like occupation level 5, in the western portion of the site level 6 can be broken into occupations 6a and 6b. Projectile points diagnostic of an Oxbow occupation were recovered from level 6b. It is hypothesized that level 6a is also associated with an Oxbow-age occupation based on the close stratigraphic association of this stratum with the Oxbow material below (Mack 2000:211). Four hearths were identified but lithic and faunal remains were sparse.

Cultural level 7 is present only in the eastern portion of the site at an average depth of 70-80 cmbs. No diagnostic cultural materials were recovered from this level. A single endscraper, some debitage, and fire broken rock constitute the entire artifact assemblage (Mack 2000:219). This level likely represented a cultural occupation that was disturbed by the lateral migration of the creek bed across the terrace, with most cultural materials swept away (Webster 1999:28).

### **2.4.3 Wolf Willow (FbNp-26)**

Cultural level 1 lies immediately below the sod to 4-12 cm below datum (cmbd) (Mampe 2015:44). Projectile points diagnostic of a Plains Side-notched occupation, Mortlach Complex pottery, and a metal musket ball were found in this level, indicating a Late Precontact or Contact age (Mampe 2015:57; Stumborg 2016:101). A radiocarbon date of  $150\pm30$  BP confirms the late age of this cultural level (Stumborg 2016:101). The high number of bifacial tools along with highly fragmented faunal remains suggests this level may reflect a short-term habitation (Mampe 2015:57).

Cultural level 2 is documented as ranging in depth from 17-29 cmbd by Mampe (2015:59), while Stumborg (2016:101) documents this level as beginning at 15-18 cmbd. Projectile points diagnostic of a Prairie Side-notched occupation were found in this level (Mampe 2015:59; Stumborg 2016:101). The artifacts recovered suggest a variety of activities took place in this level including subsistence activities and tool manufacture and repair (Mampe 2015:84). This level likely represents a spring campsite (Mampe 2015:84).

Cultural Level 3 extends approximately 28-43 cmbd (Mampe 2015:86). This level is divided into cultural level 3a, and cultural level 3. Cultural level 3a is represented by a sparse Pelican Lake occupation, defined by the recovery of a Pelican Lake projectile points recovered at 29 cmbd. Cultural level 3 yielded projectile points diagnostic of the McKean series (Mampe 2015:90-92; Stumborg 2016:125). A radiocarbon date of  $3640\pm30$  BP was obtained for this level (Stumborg 2016:57). Mampe (2015:104) interprets this level as a series of short-term primary bison processing occupations based on the high percentage of expedient tools, the faunal assemblage, and the suspected proximity of the Wolf Willow site to a bison trap or pound structure.

Cultural level 4 ranges in depth from 38-59 cmbd (Mampe 2015:106). Three projectile points diagnostic of an Oxbow occupation were found in this level (Mampe 2015:109; Stumborg 2016:139) along with a radiocarbon date of  $4540\pm30$  BP (Stumborg 2016:57). The limited

quantity of lithic and faunal remains suggests a short-term habitation with evidence of tool maintenance (Mampe 2015:114). This level was least productive in terms of cultural material. Proximity to the creek and frequent overbank flooding are likely the cause (Mampe 2015:106).

Cultural level 5 is approximately 59-80 cmbd (Mampe 2015:117). No diagnostic projectile points have been recovered from this level. A radiocarbon date of  $4860 \pm 30$  BP has been obtained (Stumborg 2016:57). The remains found in this level are mainly faunal, with two pieces of lithic shatter that may or may not show intentional modification by humans (Mampe 2015:119). It is likely these faunal remains were redeposited by fluvial action (Mampe 2015:191).

#### **2.4.4 Amisk (FbNp-17)**

Cultural level 1 is found immediately below the sod to a depth of 23 cmbs (Walker et al. 1986:36). Projectile points diagnostic of Plains Side-notched, Prairie Side-notched, and Avonlea occupations were found (Amundson 1986:61-65). This was the most productive level in terms of artifacts, accounting for nearly 50% of the lithic and faunal remains excavated at the site (Amundson 1986:83). The vertical distribution and highly fragmented nature of the faunal remains and lithic debitage suggest this level represents a series of short-term habitations (Amundson 1986:83-84). Radiocarbon dates of  $635 \pm 85$  BP from the upper portion of this level and  $905 \pm 155$  BP from the lower portion further support this suggestion (Walker et al. 1986:40).

Cultural level 2 is found from 23-40 cmbs (Walker et al. 1986:40). No culturally diagnostic artifacts were uncovered in this level, however, a radiocarbon date of  $3055 \pm 70$  BP was obtained (Walker et al. 1986:40). Of interest in this level are two buried stone circles, at least one of which is a tipi ring (Amundson 1986:102). No artifacts were found inside the stone circles, but lithic and faunal artifacts found in the level indicate lithic reduction and cooking activities took place (Amundson 1986:103).

Cultural level 3 ranges from 41-72 cmbs (Walker et al. 1986:40). No culturally diagnostic artifacts were found but a radiocarbon date of  $3530 \pm 110$  BP was obtained (Walker et al. 1986:40). The lithic artifacts and faunal remains found in this level indicate the secondary processing of bison remains.

Cultural level 4 spans 55-80 cmbs (Walker et al. 1986:38). Projectile points diagnostic of an Oxbow occupation were recovered, which is consistent with a radiocarbon date of  $4015 \pm 195$

BP (Walker et al. 1986:38). The lithic and faunal remains found at this site indicate secondary processing of bison remains. The lithic artifacts suggest tool making and repair also took place (Amundson 1986:140).

Cultural level 5 spans from 70-95 cmbs (Walker et al. 1986:38). A projectile base fragment diagnostic of an Oxbow occupation was recovered from this level along with a radiocarbon date of  $4120 \pm 190$  BP (Walker et al. 1986:38). The lithic and faunal remains found suggest this level represents secondary processing of bison from a nearby kill site (Amundson 1986:156).

Cultural level 6 is found at 80 cmbs on the east side of the site and 134 cmbs in the west part of the site (Walker et al. 1986:38). No diagnostic cultural artifacts were recovered from this level but a radiocarbon date of  $3895 \pm 195$  BP is argued to reflect an Oxbow affiliation (Walker et al. 1986:38). Artifacts from this level are scarce and lithic artifacts were restricted to debitage. This level likely represents a secondary processing site from a nearby bison kill (Amundson 1986:167).

Cultural level 7 is found at 88 cmbs on the east side of the site and 190 cmbs on the west end of the site (Walker et al. 1986:38). No culturally diagnostic artifacts have been recovered but a radiocarbon date of  $5340 \pm 120$  BP was obtained (Walker et al. 1986:38). Few artifacts were found but the faunal remains suggest this level represented a secondary bison processing site from a nearby kill (Amundson 1986:174).

#### **2.4.5 Cut Arm (FbNp-22)**

Cultural level 1 is found immediately below the sod between 0-18 cmbs and averages 5 cm in thickness (Smith 2012:38). A metal projectile point along with ceramic whitewear vessels indicates an Historic period component in this level (Smith 2012:38). The presence of Precontact pottery (cultural affiliation unknown) indicates a Precontact component to this level as well (Smith 2012:48).

Cultural level 2 appears 8-27 cmbs but averages 5.5 cm in thickness, reflecting the slope of the site (Smith 2012:51). A projectile point diagnostic of a Plains Side-notch occupation was found along with Mortlach Complex pottery. A radiocarbon date of  $524 \pm 40$  BP was obtained (Smith 2012:36). Based on the faunal and lithic artifacts recovered this level likely represents a habitation occupation (Smith 2012:62-63).

Cultural level 3 spans 18-34 cmbs and is 5 cm thick on average (Smith 2012:66). Projectile points diagnostic of a Prairie Side-notched occupation with pottery belonging to the Old Women's Phase were recovered (Smith 2012:66-67). The faunal and lithic artifacts found in this level suggest activities typical of a habitation occupation.

Cultural level 4 begins at 26-50 cmbs and is approximately 7 cm thick on average (Smith 2012:81). The presence of a Prairie Side-notched projectile point and possible Avonlea pottery indicates a Late Precontact period occupation (Smith 2012:81). The sparse assemblage of lithic, faunal, and pottery artifacts suggest this was a short-term habitation (Smith 2012:95-96).

Cultural level 5 is divided into three discrete occupations, 5a, 5b, and 5c; the depths of each level are impacted by the strong slope of the site. Level 5a is found from 36-61 cmbs but is never thicker than 4.5 cm. Projectile points diagnostic of a Besant occupation were found in level 5a. Level 5b is found from 55-78 cmbs and is 5 cm thick. Level 5c is found from 68-78 cmbs and is 6 cm thick. No culturally diagnostic artifacts were recovered from levels 5b or 5c (Smith 2012:99-100).

Cultural level 6 spans 68-100 cmbs but is only 5.5 cm in maximum thickness (Smith 2012:119). No diagnostic cultural artifacts were recovered from this site but a radiocarbon date of  $3178 \pm 50$  BP (Smith 2012:36) places this level within the McKean series (Smith 2012:119). The lithic and faunal remains recovered from this level indicate a short-term fall occupation. Cultural level 7 ranges from 80-113 cmbs but is only 6 cm thick (Smith 2012:133). No culturally diagnostic artifacts were recovered. Radiocarbon dates of  $3178 \pm 50$  BP and  $3387 \pm 50$  BP (Smith 2012:36) from levels 6 and 8 respectively confine the dates for this occupation.

Cultural level 8 appears between 103-136 cmbs and is 7.5 cm thick on average (Smith 2012:143). One projectile point diagnostic of a McKean occupation was recovered from this level. Radiocarbon dates of  $3387 \pm 50$  BP and  $3448 \pm 60$  BP (Smith 2012:36) support this affiliation. The lithic and faunal remains found in this level suggest the main activity of this occupation was bison processing (Smith 2012:154-155).

Cultural level 9 is found between 123-179 cmbs but is only 6 cm thick, again a result of the high degree of sloping to the site (Smith 2012:158). A projectile point diagnostic of an Oxbow occupation was recovered from this level along with a radiocarbon date of  $3802 \pm 55$  BP (Smith 2012:36). There is a scarcity of other lithic and faunal remains in this level, which may be

the result of hillslope processes and erosion removing cultural materials from the site (Smith 2012:166).

Cultural level 10 ranges in depth from 147-198 cmbs but is only 7 cm in average thickness (Smith 2012:169). One Early Side-notched projectile point was found in this level, indicating an Early Middle Precontact period occupation (Smith 2012:196). The other lithic and faunal remains found in this level suggest this was a short-term occupation (Smith 2012:176). Cultural level 11 spans from 175-225 cmbs but the cultural level is only 5.5 cm thick on average. No culturally diagnostic artifacts were recovered.

#### **2.4.6 Tipperary Creek (FbNp-1)**

Cultural level 1 is found 5-10 cmbs (Walker et al. 1987:25). A Plains Side-notched and a metal trade point indicating a Contact era occupation were found in this level (Harty 2005:42; Walker et al. 1986). A radiocarbon date of  $<100$  BP supports this assignment (Walker et al. 1987:25). Also recovered were other trade artifacts including metal and glass (Harty 2005:56-57).

Cultural level 2 begins at 25 cmbs (Walker et al. 1987:25). Projectile points diagnostic of Plains Side-notched and Plains Triangular occupations and a radiocarbon date of  $380 \pm 70$  BP have been recovered from this level (Walker et al. 1987:27). Cultural level 3 starts at 50 cmbs (Walker et al. 1987:27). Projectile points diagnostic of a Plains Side-notched occupation along with pottery belonging to the Mortlach Complex have been recovered from this level. A radiocarbon date of  $200 \pm 70$  BP has also been obtained (Walker et al. 1987:27).

Cultural level 4 starts at 55 cmbs (Walker et al. 1987:29). Projectile points diagnostic of a Plains Side-notched occupation along with pottery belonging to the Mortlach Complex were found in this level. A radiocarbon date of  $290 \pm 70$  BP has also been obtained (Walker et al. 1987:29). Cultural level 5 is located at 60 cmbs. Projectile points diagnostic of a Plains Side-notched occupation along with pottery belonging to the Mortlach Complex were found in this level. A radiocarbon date of  $510 \pm 70$  BP has also been obtained (Walker et al. 1987:29). Cultural level 6 begins at 65 cmbs. Projectile points diagnostic of a Prairie Side-notched occupation and a radiocarbon date of  $790 \pm 135$  BP were recovered from this level (Walker et al. 1987:32).

Cultural level 7 starts at 68 cmbs (Walker et al. 1987:32). Projectile points diagnostic of a Prairie Side-notched occupation along with a radiocarbon date of  $855 \pm 70$  BP have been



recovered from this level (Walker et al. 1987:32). Cultural level 8 appears at 71 cmbs (Walker et al. 1987:34). No diagnostic projectile points were found in this level, however, pottery sherds diagnostic of Old Women's Phase were recovered (Harty 2005:65). A radiocarbon date of  $800\pm70$  BP was obtained from this level (Walker et al. 1987:34). Cultural level 9 begins at 83 cmbs (Walker et al. 1987:34). No diagnostic projectile points were found in this level, however, pottery sherds diagnostic of the Old Women's phase were recovered (Harty 2005:65). A radiocarbon date of  $945\pm135$  BP was obtained from this level (Walker et al. 1987:34).

Cultural level 10 appears at 92 cmbs. A Late Side-notched projectile point recovered from this level and a radiocarbon date of  $1155\pm75$  BP indicates a Late Precontact occupation (Walker et al. 1987:37). Other artifact types in this level are sparse. Cultural level 11 starts at 96 cmbs (Walker et al. 1987:37). Pottery sherds diagnostic of an Avonlea occupation were recovered (Harty 2005:110). A radiocarbon date of  $1235\pm75$  BP from this level indicates a Late Prehistoric occupation (Walker et al. 1987:37).

Cultural level 12 is found at 105 cmbs. A projectile point diagnostic of an Avonlea occupation was recovered. A radiocarbon date of  $1790\pm75$  BP has also been recovered from this level (Walker et al. 1987:37). Cultural level 13 begins at 115 cmbs. Projectile points diagnostic of an Avonlea occupation were recovered from this level along with a radiocarbon date of  $1505\pm75$  BP (Walker et al. 1987:38). The few lithic and faunal remains found in cultural levels 14-18 were likely redeposited by fluvial processes (Walker et al. 1987:38).

## **2.5 Current Climate, Soils, and Vegetation**

WHP is located within the Saskatchewan Plain in the Moist Mixed Grassland ecoregion of Saskatchewan, close to the southern boundary of the Aspen Parkland ecoregion (Figure 2.3). The Moist Mixed Grassland ecoregion is characterized by open expanses of mixed tall and shortgrass prairie. Hummocky moraines, sand dunes, hilly uplands, deeply incised river valleys, and coulees break up the region creating a diverse and scenic landscape (Acton et al. 1998:142). The Aspen Parkland ecoregion to the north is a transition zone between the open grasslands to the south and the Boreal Forest to the north. This ecoregion is characterized by aspen groves and mixed tall shrubs interspersed with open fescue grasslands. This region is mostly open plains broken up by deep valleys and upland regions (Acton et al. 1998:125).



Figure 2.3: Ecoregions of Saskatchewan (Canadian Plains Research Center Mapping Division 2016, modified by author). Note the arrow showing the location of Wanuskewin Heritage Park.

### 2.5.1 Modern Climate

Currently, the Saskatoon region experiences a sub-humid to humid continental climate characterized by long, cold winters, and short, warm summers. Based on data collected from 1981-2010, January, the coldest month, has a daily average temperature of  $-13.9^{\circ}\text{C}$  and an average daily minimum of  $-18.9^{\circ}\text{C}$ . July is the warmest month with a daily average temperature of  $19^{\circ}\text{C}$  and an average daily maximum of  $25.7^{\circ}\text{C}$  (Environment Canada 2016). On average, Saskatoon experiences 1658 annual growing degree days. The region experiences an average of 164 frost-free days (Fung 1999) and is typically frost-free from May 21 to September 15 but due to its northerly location frosts may occur as late as June and as early as August (Environment

Canada 1981). The mean annual precipitation is 340 mm (Environment Canada 2016) with the majority falling as rainfall between the months of May to September with approximately 100 mm of snowfall from October to April (Acton et al. 1998). The wettest month is July with an average of 63 mm of rainfall while the driest month is February with an average of 9 mm of snowfall (Environment Canada 2016). Saskatoon is one of the sunniest regions in Canada, experiencing approximately 2381 hours of sunshine annually (Fung 1999).

Winds predominantly approach the prairies from the west as a result of the global circumpolar westerly winds. In the winter, the Polar Jetstream forces cold arctic air across the prairies from a northwest direction. As summer approaches the Polar Jetstream migrates northward as winds from the warm Pacific air mass blow northeastward and bring spring precipitation to the prairies. The hot, dry summer winds experienced on the prairies originate in the American southwest. These winds carry with them dust and sand and wick moisture from the surface and carry away topsoil (Phillips 1990; Vickers et al. 2000).

### **2.5.2 Soils**

Soils within WHP classified as belonging to the Hillwash Complex are made up of a mixture of Regosolic, Chernozemic, and Podzolic soils (Acton and Ellis 1978). Regosolic soils are well to imperfectly drained mineral soils that lack well-developed soil horizons. They are most commonly associated with unstable landforms where periods of soil formation are limited. Regosols are commonly found on floodplains and hillslopes where they are disturbed by alluvial deposits and hillslope processes including slope wash (Canadian Society of Soil Science 2016). Chernozemic soils are well to imperfectly drained soils with thick, dark coloured Ah horizons and B and C horizons rich in carbonates. Chernozemic soils are dominant in the grassland region of Canada (Canadian Society of Soil Science 2016). Podzolic soils are well to imperfectly drained soils with prominent B horizons rich in aluminum and iron oxides. Intense weathering results in a characteristic light grey Ae horizon. These soils are typically associated with forest vegetation (Canadian Society of Soil Science 2016). Regosolic and Chernozemic soils are commonly identified throughout WHP, while Podzolic soils are not commonly identified.

The soils on the surrounding uplands are part of the Bradwell Association to the west and the Weyburn Association to the east. Soils of the Bradwell Association are defined as Chernozemic Dark Brown soils that are formed under grassland vegetation. Adjacent to the Opimihaw Creek Valley the soils of the Bradwell Association are part of the Orthic Brown series

which are typically loamy in texture and have thick Ah horizons. These soils are formed on undulating glaciolacustrine landforms, consistent with the geomorphic history of the region (Acton and Ellis 1978). To the west, soils of the Weyburn Association are also Chernozemic Dark Brown soils formed under grassland vegetation. Adjacent to the Opimihaw Creek Valley these soils are part of the Orthic Dark Brown series with significant portions represented by the Calcareous Dark Brown series. These soils often form on undulating knoll and depression glacial till plains (Acton and Ellis 1978).

### **2.5.3 Modern Vegetation**

The Opimihaw Creek Valley has been divided into three main vegetation zones: Upland Prairie, Valley Slope, and Floodplain (Walker 1983:7-9). The relative presence of natural grassland, shrubs, and tree groves are influenced by the topography, moisture availability, and sun exposure of each zone. The boundaries between these vegetation zones are subtle and some species may be present in one or more zones. WHP has remained relatively unaffected by agriculture and urban development, however, the surrounding uplands have been modified by agriculture. Introduced plant species including dandelions (*Taraxacum officinale*), smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), and Canada thistle (*Cirsium arvense*) have been identified within the valley.

Table 2.1: Table of scientific and common names of plant species in Section 2.5.

Scientific Name	Common Name	Scientific Name	Common Name
<i>Acer negundo</i> (L.)	Manitoba maple	<i>Hesperostipa comata</i> (Trin. & Rupr.)	Needle and thread grass
<i>Achillea millefolium</i> (L.)	Common yarrow	<i>H. curtisetia</i> (Hitchch.)	Western porcupine grass
<i>Agropyron cristatum</i> (L.)	Crested wheatgrass	<i>Juniperus horizontalis</i> (Moench)	Creeping juniper
<i>A. dasystachyum</i> (Hook)	Northern wheat grass	<i>Koeleria cristata</i> (Pers.)	June grass
<i>A. smithii</i> (Rydb.)	Western wheatgrass	<i>Mentha</i> spp (L.)	Mint
<i>Amelanchier alnifolia</i> (Nutt.)	Saskatoon berry	<i>Nassella viridula</i> (Trin.)	Green needle grass
<i>Anemone patens</i> (L.)	Prairie crocus	<i>Phlox hoodia</i> (Richardson)	Moss phlox
<i>Artemisia campestris</i> (L.)	Plains wormwood	<i>Populus balsamifera</i> (L.)	Balsam poplar
<i>A. frigida</i> (Willd.)	Pasture sage	<i>P. tremuloides</i> (Michx.)	Trembling aspen
<i>A. ludoviciana</i> (Nutt.)	Prairie sage	<i>Prunus virginiana</i> (L.)	Chokecherry
<i>Bouteloua gracilis</i> (Kunth)	Blue grama grass	<i>Ribes oxycanthoides</i> (L.)	Northern gooseberry
<i>Bromus inermis</i> (Leyss.)	Smooth brome	<i>Rosa acicularis</i> (Lindl.)	Prickly wild rose
<i>Carex aquatilis</i> (Wahlenb.)	Water sedge	<i>R. arkansana</i> (Porter)	Prairie rose
<i>C. eleocharis</i> (L.H. Bailey)	Low sedge	<i>R. woodsia</i> (Lindl.)	Woods rose
<i>C. filifolia</i> (Nutt.)	Thread-leaved sedge	<i>Scirpus</i> spp (L.)	Rushes
<i>C. pensylvanica</i> (Lam.)	Sun-loving sedge	<i>Sium suave</i> (Walter)	Water parsnip
<i>Carex</i> spp. (L.)	Sedges	<i>Solidago canadensis</i> (L.)	Canada goldenrod
<i>Cirsium arvense</i> (L.)	Canada thistle	<i>Sphaeralcea coccinea</i> (Nutt.)	Scarlet mallow
<i>Elaeagnus commutata</i> (Bernh. ex Rydb.)	Wolf willow	<i>Symphoricarpos occidentalis</i> (Hook)	Western snowberry
<i>Elymus canadensis</i> (L.)	Canada wild rye	<i>Taraxacum officinale</i> (F.H. Wigg)	Dandelion
<i>Equisetum arvense</i> (L.)	Common horsetail	<i>Typha latifolia</i> (L.)	Common cattail
<i>Fraxinus</i> spp (L.)	Ash	<i>Urtica dioica</i> (L.)	Common nettle
<i>Galium boreale</i> (L.)	Northern bedstraw	<i>Viola</i> spp (L.)	Violet

### 2.5.3.1 Upland Prairie Zone

The Upland Prairie Zone is classified as the area that is significantly higher than the level of the proximal water source. The vegetation in this zone is largely composed of native grasses of the *Stipa-Agropyron* complex (Walker 1983:7). The dominant species in the upland zone are needle and thread grass (*Hesperostipa comata*) and northern wheat grass (*Agropyron dasystachyum*). Other grasses present include june grass (*Koeleria cristata*), western porcupine grass (*Hesperostipa curtiseta*), western wheatgrass (*Agropyron smithii*), green needle grass (*Nassella viridula*), and blue grama grass (*Bouteloua gracilis*) (Budd and Best 1964; Native Plant Society of Saskatchewan 2012; Thorpe 2014). A variety of sedges are also present, including low sedge (*Carex eleocharis*), thread-leaved sedge (*C. filifolia*), and sun-loving sedge (*C. pensylvanica*), as are various forbs like pasture sage (*Artemisia frigida*), prairie sage (*A. ludoviciana*), scarlet mallow (*Sphaeralcea coccinea*), prairie crocus (*Anemone patens*), and moss phlox (*Phlox hoodii*). Shallow depressions on the uplands that retain moisture support shrub species that can include western snowberry (*Symphoricarpos occidentalis*), Saskatoon berry (*Amelanchier alnifolia*), prickly wild rose (*Rosa acicularis*), and prairie rose (*R. arkansana*) (Budd and Best 1964; Native Plant Society of Saskatchewan 2012; Walker 1983:7). Moist depressions on the uplands can also support immature stands of trembling aspen (*Populus tremuloides*).

### 2.5.3.2 Valley Slope Zone

The Valley Slope Zone is transitional between the Upland Prairie Zone and the Floodplain Zone. This includes the stable and unstable slopes of the Opimihaw Creek Valley. Stable slopes are vegetated by Mixed Deciduous Tree/Shrub and Poplar/Shrub Associations (Walker 1983:8). Dominant arboreal species include Manitoba maple (*Acer negundo*), balsam poplar (*Populus balsamifera*), trembling aspen, and chokecherry (*Prunus virginiana*) (Meewasin Valley Authority 1984; Native Plant Society of Saskatchewan 2012). Shrubs present include northern gooseberry (*Ribes oxycanthoides*), western snowberry, woods rose (*Rosa woodsii*), wolf willow (*Elaeagnus commutata*), creeping juniper (*Juniperus horizontalis*), and Saskatoon berry (Meewasin Valley Authority 1984; Native Plant Society of Saskatchewan 2012). Canada wild rye (*Elymus canadensis*), northern bedstraw (*Galium boreale*), common horsetail (*Equisetum arvense*), violet (*Viola spp.*), and prairie crocus are common ground cover species. The vegetation of unstable slopes resembles that of the Upland Prairie Zone. Common species

include pasture sage, plains wormwood (*A. campestris*), common yarrow (*Achillea millefolium*), june grass, common broomweed (*Gutierrezia sarothrae*), Canada goldenrod (*Solidago canadensis*), and prairie rose (Meewasin Valley Authority 1984; Native Plant Society of Saskatchewan 2012).

#### **2.5.3.3 Floodplain Zone**

The Floodplain Zone is classified as the lowland area where vegetation is related to the inundation of floodwaters. The area is characterized by distinct landform features including terraces, point bars, and low-lying areas adjacent to the creek channel that support different vegetative communities. Terraces are populated by Manitoba maple, ash (*Fraxinus* spp.), trembling aspen, balsam poplar, chokecherry, Saskatoon berry, and wolf willow. Bedstraw, wheat grass, needle and thread grass, common nettle (*Urtica dioica*), and sedges (*Carex* spp.) are common in the understory. Low-lying areas of the valley support riparian vegetation that thrives in moist soil conditions. Water sedge (*C. aquatilis*), common cattail (*Typha latifolia*), water parsnip (*Sium suave*), rushes (*Scirpus* spp.), and mint (*Mentha* spp.) are common species found in low-lying areas (Meewasin Valley Authority 1984).

## CHAPTER 3

### THE UTILITY OF PHYTOLITHS AS A PALEOENVIRONMENTAL INDICATOR

#### 3.1 Introduction

Phytoliths are resilient, microscopic particles composed of hydrated silica ( $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ ) that are preserved in situ after the death and decay of members of certain plant taxa. “They are the most durable plant fossil known to science” (Piperno 2006:5). Due to their high survival rate and variable morphology they are very suitable for paleoenvironmental reconstructions. Analysis of phytolith morphology provides the potential to identify specific plant taxa (Bozarth 1993; Brown 1984; Rovner 1971) and this information allows for the reconstruction of past vegetation and can therefore infer paleoclimatic conditions. For this reason, phytoliths have been an attractive avenue of study for paleoecologists and archaeologists since the initial discovery of these particles approximately 180 years ago. This chapter will explain the origins of phytoliths within plant material, outline the history of phytolith research, and discuss the utility of phytoliths as paleoenvironmental proxies.

#### 3.2 Phytoliths

Phytoliths are formed when monosilicic acid ( $\text{H}_4\text{SiO}_4$ ) is taken up by a plant’s root system and transported through the xylem to the aerial organs (leaves and leaf tissues) where it is deposited most commonly in the epidermal cells. Phytoliths also occur in fewer numbers in the stem, bark, and root portions of some species (Rovner 1971). Silica is deposited within the cell walls, lumen, and intercellular spaces, and in some cases entire cells may become silicified (Sangster et al. 2001). Commonly silicified cells in the grass family include short cells, long cells, bulliform cells, trichomes, and stomatal guard cells (Bozarth 1993). The depositional location of silica within a plant body controls the size and shape of phytoliths (Piperno 2006:24). This results in phytoliths exhibiting a variety of morphological characteristics between different parts of a given plant and in morphological variation of phytoliths between species (Rovner 1983). It is these specific morphological differences that give phytoliths their taxonomic value.



Phytoliths are one form of biogenic silica. Biogenic silica has been referred to as opal, biogenic opal, or amorphous silica (which also occurs outside of biogenic contexts), all of which are terms that describe silica present in plants and animals (Piperno 2006:5). Silica in plants has been referred to as opal phytoliths, plant opal, and opaline silica. These names reflect the fact that phytoliths share a number of properties with and are chemically identical to hydrated silica or amorphous silica, which is also known as opal (Piperno 2006:5). Like silica, phytoliths have a high resistance to decay (Piperno 2006:5) and have been found in contexts dating as far back as the Cretaceous period (Piperno & Sues 2005). They remain stable in most depositional contexts, including very acidic conditions. Phytoliths have been found to be insoluble in environments with a pH of 3 and may remain unaltered up to a pH of 9 but become soluble in conditions of pH 10 or higher (Cabanès et al. 2011; Fraysse et al. 2006).

The specific gravity of phytoliths ranges from 1.5-2.3 (Dunn 1983; Jones & Beavers 1963) and they have a refractive index of 1.41-1.46 (Jones & Beavers 1963). Phytoliths range in size from 2-1000  $\mu\text{m}$  but most fall within the 20-200  $\mu\text{m}$  range (Rovner 1971). Few phytoliths larger than 250  $\mu\text{m}$  occur and these are mainly multicellular aggregates of phytoliths from domestic cereal crops (Piperno 2006:91). Phytoliths used for paleoecological reconstruction most commonly fall within the 5-50  $\mu\text{m}$  range (Fishkis et al. 2010). Phytoliths range in colour from colourless to tinted brown to black (Jones & Beavers 1963). The brown/black colouration is attributed to the presence of cellular organic matter trapped within the phytolith (Jones & Beavers 1963). As phytoliths become silicified bits of cellular material may become trapped within the phytolith (Section 5.1). As a result, the composition of phytoliths may include other trace elements (Hart 2001).

The purpose of phytolith production within plants is not completely understood. It has been suggested they may relate to rigidity of the plant or to protection from herbivory (Piperno 2006:12-13). Not all plant species produce phytoliths and there is significant variability in the quantity of phytoliths produced between taxa. Angiosperms, or flowering plants, are the most diverse group of land plants and are divided into two major groups, monocotyledons and dicotyledons. Monocotyledons are among the most abundant producers of phytoliths. This group includes the Poaceae (grass) family, one of the most abundant phytolith-producing families. Certain dicotyledons, including some deciduous trees and shrubs, produce phytoliths, however, other dicotyledons produce no phytoliths at all. Some of the most important phytolith-producing

plant families on the Northern Plains are the Poaceae, Cyperaceae, and Asteraceae, and to a lesser extent several species of conifers and deciduous trees (Blinnikov et al. 2013). For additional information on phytolith production in different plant taxa see Pearsall (2010:360-374) or Piperno (2006:7).

### **3.3 Deposition and Taphonomy**

Phytoliths are deposited into the sedimentary record mainly by decay-in-place mechanisms. When a plant dies, the organic tissues break down and become incorporated into the soil profile. The inorganic constituents, including phytoliths, become disassociated from the plant body and are also incorporated into the soil profile. For this reason, phytoliths are often considered to be a reflection of local vegetative histories, which makes them an excellent candidate for the reconstruction of local environments (Piperno 1988:142; Rovner 1983). Typically, phytoliths represent between 1-3% of the total sediment weight (Clarke 2003; Sudbury 2010).

Upon deposition, phytoliths are exposed to the transport processes of wind and water. Phytoliths have been recovered from wind-blown sediments and atmospheric dusts (Folger et al. 1967; Twiss et al. 1969) which indicates the potential for transportation across long distances. Despite this potential for transport, researchers have documented that relatively few phytoliths in a given assemblage are the result of horizontal translocation and that phytolith assemblages accurately reflect the composition of extant vegetative communities at the location of deposition (Blinnikov et al. 2013; Fisher et al. 1995, Twiss et al. 1969). This has been achieved through the analysis of modern, adjacent plots of differing vegetation types. The phytolith assemblages of these plots typically represent the above-ground vegetation of each individual plot and do not appear to reflect the horizontal translocation of phytoliths from adjacent plots of differing vegetation types (Blinnikov et al. 2013; Fisher et al. 1995; Twiss et al. 1969). The effects of water on the horizontal transport of phytoliths have yet to be thoroughly addressed (Mulholland 1989).

Vertical translocation of phytoliths due to pedogenesis and water percolation may have an effect on phytolith assemblages. Both processes may result in the downward migration of particles through a soil or sediment profile (Waters 1992:41-42). Phytoliths used in paleoecological reconstructions have been shown to be less likely to move vertically within a soil profile (Fishkis et al. 2010). There is, however, an observed tendency for phytoliths to appear in

higher concentrations in poorly drained than well-drained soils (Clarke 2003; Jones & Beavers 1964b). Studies have shown that phytoliths are a good indicator of soil A horizons and that phytolith concentrations decrease with depth (Jones et al. 1963; Jones et al. 1964). It is worth noting that Piperno (2006:111-115) dismisses translocation of phytoliths as a strong factor in phytolith taphonomy.

### **3.4 A History of Phytolith Research**

The history of phytolith analysis is generally divided into five distinct periods: The Discovery and Explanatory Period (1835-1895), The Botanical Research Period (1895-1936), The Ecological Research Period (1955-1975), The Period of Modern Phytolith Research (1975-2001), and The Period of Expanding Applications (2001-Present) (Hart 2016; Piperno 2006). These periods are defined by the outcomes and objectives of studies undertaken during each period and reflect the focus of phytolith research at different times throughout history. Review of this research leads to the conclusion that the analysis and interpretation of phytolith deposits in soils and sediments has a wide variety of applications in paleoenvironmental reconstruction. The use of these particles as proxy environmental indicators continues to become more diverse as researchers continue to discover ways to explore the information these microscopic bodies can provide.

#### **3.4.1 The Discovery and Exploratory Period (1835-1895)**

Phytoliths were first observed in living plants in 1835 by German botanist G.A. Struve, one year before pollen grains were first discovered in pre-Quaternary sediments (Bryant 1993; Faegri & Iversen 1975). Around this time microbiologist C.G. Ehrenberg, a fellow German, observed siliceous bodies inside living plant tissues and soil samples collected from around the world (Piperno 1988, 2006; Powers 1992). Originally, Ehrenberg believed the siliceous bodies belonged to skeletons of microorganisms living within plants but later recognized that many forms were silicified plant tissues. He named these silica bodies “*Phytolitharia*”, Greek for “plant stone” (Powers 1992). Despite first being named “*Phytolitharia*” by Ehrenberg, in 1866 Franz Joseph Ruprecht defined the term phytolith “as the microscopic opaline bodies deposited in plants” (Mulholland and Rapp 1992a:2) and this is the term in use today. Ehrenberg was the first to recognize that phytoliths were identifiable to specific plant families and developed the

first phytolith classification system, published in *Mikrogeologie* in 1854, which documented several dozen morphologies (Piperno 1988).

On the “Voyage of the Beagle” in 1833 Charles Darwin noticed a hazy atmosphere caused by a very fine dust. Curious about the cause, Darwin collected samples of the dust filtered out of the air by the thin sails of the H.M.S. Beagle and sent them to Ehrenberg for analysis. Ehrenberg confirmed these samples contained phytoliths, which made Darwin the first person to sample phytoliths in aerosols (Piperno 1988, 2006). While Ehrenberg was not the first person to discover phytoliths, because of his pioneering work in the field of phytolith research, he is considered the “father of phytolith studies” (Powers 1992).

### **3.4.2 The Botanical Research Period (1895-1936)**

It was during the Botanical Research Period that the taxonomic utility of phytoliths was recognized by botanists. Studies identifying the presence of silica bodies, or “*Kieselkörper*”, in living plant tissues increased mainly through the research of German scholars including Grob 1986, Haberlandt 1914, Mobius 1908, and Neolitsky 1929 (cited in Piperno 1988, 2006). A significant amount of information on phytolith production, morphological types, taxonomy, and intraspecific variation was published during this period. A major focus of research was the identification of phytolith-producing plant families and the morphological characteristics that would identify phytoliths as belonging to specific plant taxa (Piperno 1988; Powers 1992). Unfortunately, as much of the research during this period was published in German, it was inaccessible to and largely ignored by English-speaking scientists (Piperno 1988, 2006).

During this period focus was placed on the analysis of living plant material in order to learn where phytoliths are deposited within plant tissue and what functions silica deposits might play in plant physiology. For reasons that are still not understood, it has been found that phytoliths tend to be produced in higher quantities in epidermal cells (Solereder 1908) and production is particularly high in the reproductive structures of plants (Piperno 2006). A number of phytolith-producing plant families were identified during this period, including many ferns, nettles, and grasses. A heavy focus was placed on the analysis of phytoliths from cereal grains and other members of the Poaceae family (Piperno 1988). It has been suggested that attention focused on cereal grains because of their economic and agricultural importance as well as the diverse range of environments they occupy and the sheer abundance of this genera (Powers 1992).

The first application of phytolith research in archaeological investigations took place during this period. In the early twentieth century, German scholar F. Netolitzky studied soils from European archaeological sites to discover locations where early farming was practiced, based on the presence of wheat and barley phytoliths (Bryant 1993). It was also Netolitzky that confirmed the cultural use of a number of plant species in Europe based on the presence of phytoliths in archaeological sediment samples (Bryant 1993). Phytoliths provide an opportunity to document the presence of domesticated plants such as wheat, barley, and millet as the morphology of phytoliths from domesticated plants differ from those of wild progenitors (Bryant 1993; Piperno 1988, 2006).

### **3.4.3 The Ecological Research Period (1955-1975)**

The Ecological Research Period was characterized by the recognition of the potential of accumulated phytoliths in sediments to aid in paleoecological reconstructions. This was catalyzed by the work of Russian soil scientists such as Tyurin (1937), Usov (1943), Parfenov (1956), and Yarilova (1956), who during the Botanical Research Period studied the accumulation and presence of phytoliths in Russian soils (reviewed in Powers 1992; Smithson 1958). F. Smithson (1956, 1958) was one of the first scholars to recognize and study phytoliths in British soils (Powers 1992) and one of the first phytolith researchers to publish his findings in English. Smithson (1956) highlighted the potential of these silica particles to provide information on past soil formation and vegetation histories. In 1958 he identified phytoliths in soils as belonging to specific genera of grasses and published approximately 150 drawings of the types he found (Smithson 1958).

With the presence of phytoliths in soils now documented in English publications, studies identifying and documenting silica bodies in soils by English-speaking scientists began to flourish. After reviewing Smithson's work, Baker (1959) admitted the silica bodies from Australian soils he and other scholars identified as diatom and sponge spicules were in fact phytoliths. Hydrated silica deposited in diatoms, radiolarians, and some sponge spicules are chemically identical to phytoliths but differ in morphology and are therefore visually distinguishable from phytoliths (Clarke 2003). Beavers and Stephen (1958) were among the first North American scholars to recognize small grains from soil samples as phytoliths based on their similarity to images published by Smithson (1956). Beavers and Stephen (1958) also identified the potential of phytoliths to serve as an "index mineral" for the identification of soil A horizons,

based on evidence indicating phytoliths appear in higher concentrations in soil A horizons compared to B and C horizons of the same soil. In this way phytoliths can be used as an indicator, or “index mineral”, to identify times of past landscape stability and soil formation (Beavers & Stephen 1958).

Once phytoliths were recognized as a component of sediments in North America, studies began to explore the utility of phytoliths for interpreting vegetation histories and developing paleoecological reconstructions. In North America, phytoliths were also found to be a particularly useful proxy to identify the past presence/absence of grassland or forest vegetation in transitional vegetation zones such as the Great Plains/Eastern Temperate Forest boundary of the United States (Jones & Beavers 1964a; Verma & Rust 1969; Wilding & Drees 1971). Bulk quantities of phytoliths were analyzed as phytolith taxonomy was not well developed at this time. Based on the high abundance of phytoliths in grasses relative to forest vegetation, the presence of grass vegetation was inferred in paleosols with high concentrations of phytoliths in comparison to paleosols in other soil profiles in the region.

As the study of phytoliths in both living plant specimens and terrestrially derived sediments increased, a number of quirks in regard to phytolith morphology were recognized. It was known since Ehrenberg began his studies in the 1800s that phytoliths were produced in many different shapes (cited in Mulholland and Rapp 1992a and Piperno 1988, 2006) and work during the Ecological Period sought to assign specific shapes to specific plant taxa. In particular, researchers during the Ecological Period were interested in the discrimination of phytoliths to better identify plant taxa present in ancient soils. The ideal outcome of this research was to assign specific phytolith shapes to plants at the species or genus level. Few distinct taxonomic assignments were made until the late 1960s and 1970s (Rovner 1971). This was in part due to the multiplicity (single plant species can produce more than one shape of phytolith) and redundancy (a single morphological type can be present in more than one species) of phytolith types (Metcalf 1960; Mulholland 1989; Rovner 1983). Despite these difficulties, descriptive studies of phytoliths from soils and living plant species continued and the foundations of modern comparative techniques were laid.

Grass species were most commonly studied, including work done by Blackman (1971), Parry and Smithson (1958, 1964), Verma and Rust (1969), and Wilding and Drees (1971). Some of the most notable publications in regard to phytolith taxonomy are those of Metcalf's (1960)

volume detailing the various forms of silica bodies and their locations within monocots, and Twiss, Suess, and Smith's (1969) morphological classification scheme of grass phytoliths that is still widely referenced today.

A number of studies documenting the survival of phytoliths on a deep-time scale were also undertaken during the Ecological Period. Phytoliths were recovered from Wisconsin-age loess (Jones et al. 1963), Pleistocene sediments (Wilding 1967), Pliocene sediments (Gill 1967), and deposits from the Cenozoic (Jones 1964). Phytoliths were also identified in a variety of contexts including deep-sea cores from the Atlantic Ocean (Parmenter & Folger 1974) and atmospheric dust (Baker 1960; Twiss et al. 1969). The discovery of phytoliths in sediments millions of years old, coupled with the confirmation of their presence in contexts other than terrestrial soils, speaks to the resilient nature and wide utility of phytoliths to aid paleoenvironmental research.

#### **3.4.4 The Modern Period of Paleoenvironmental Research (1978-2000)**

During this period, research into the use of phytoliths as environmental proxies intensified. The ability of researchers to use phytoliths to reconstruct past vegetation and climate became an attractive aspect of phytolith research for paleoecologists and archaeologists alike. Archaeologists embraced the utility of phytoliths as an indicator of the use and availability of wild plant resources, the origins of agriculture and plant domestication, and stone tool and pottery function (Pearsall 1982; Piperno 2006; Rovner 1983). Unlike the Ecological Period, research by European scholars was quite stagnant at the onset of the Modern Period (Powers 1992). Instead, the driving force of phytolith research came from American scholars interested in the application of phytolith studies to the investigation of the paleoecology and archaeology of North and South America (Piperno 2006).

Research into phytolith taxonomy during the Ecological Period, particularly the work by Twiss et al. (1969), increased the interpretive value of phytoliths as paleoenvironmental indicators. Due to improvements in taxonomic identification, researchers were no longer restricted to inferences about the presence/absence of vegetation. Most work on the Northern Plains focused on the analysis of short-cell grass phytoliths, though studies involving non-grass phytoliths increased during this period as more taxonomic relationships were recognized. Important early publications from North America during this period focused on the reconstruction of Quaternary vegetation of the Plains and Eastern Woodlands (e.g. Fisher et al.

1995; Fredlund & Tieszen 1994; Kurmann 1985) and how those changes influenced early human occupations of these areas (e.g. Carbone 1977; Lewis 1979). Other important work in North America included extensive work on the identification of domesticates in early horticultural societies of the United States (Bozarth 1987, 1990; Mulholland 1993). In South America, phytolith studies concentrated on questions of domestication with a focus on maize agriculture and other major domesticates such as Cucurbitaceae and Fabaceae (see Piperno 2006:140-152 for a detailed overview of phytolith studies in South America).

It was known from research during the Ecological Period that phytoliths contain a small amount of occluded cellular carbon and could be suitable for obtaining radiocarbon dates (Jones & Beavers 1963; Wilding 1967). Unfortunately, due to technology at the time, phytolith samples weighing tens of grams were required to provide enough carbon for a radiocarbon date (Wilding 1967). For this reason, the potential of phytoliths to provide radiocarbon dates was noted throughout the Ecological Period but not expanded upon until the Modern Period. Technological advances related to the study of isotopes allowed Kelly et al. (1991) to revisit the potential of phytolith occluded carbon and its ability to provide radiocarbon dates via Accelerator Mass Spectrometry (AMS). Kelly et al. (1991) also introduced a new way in which phytoliths can aid in paleoenvironmental reconstructions - by measuring the isotopic composition of occluded carbon to produce a  $\delta^{13}\text{C}$  value. The use of stable carbon isotopes from phytoliths will be discussed in greater detail in Chapter 5.

### **3.4.5 The Period of Expanding Applications (2001-Present)**

The Period of Expanding Applications began in 2001 when a global increase in the number of phytolith publications and a diversification of research topics became apparent. In a survey of publications in English-language journals with the word “phytolith” in the title Hart (2016) found the average number of publications between 1997 and 2015 had increased to 13.58 (std  $\pm 8.71$ ) publications per year from an average of 1.03 (std  $\pm 1.61$ ) publications per year from 1971 to 1996. This overall increase in publications is directly tied to the diversification of applicable topics of phytolith research. Phytoliths have been used in the analysis of plant use by early *Homo sapiens* and other hominins, spatial organization and activity patterns, anthropogenic burning, disturbance regimes, and hunter-gatherer foodways (Pearsall 2015). The application of



phytolith research during this period extended to paleontology, paleobotany, and primatology among other disciplines.

The analysis of phytoliths from both ancient sediments and modern contexts speaks to the utility of phytoliths as indicators of diet and vegetation. Phytoliths have been discovered in Miocene-age sediments in North America providing evidence of the dominance of C<sub>3</sub> grasses on the continent prior to 16 million years ago (Strömberg 2002). They have also been found in dinosaur coprolites from the Cretaceous period and were used to study the relationship between grass evolution and herbivore diet (Piperno & Sues 2005). In modern contexts, phytoliths from primate feces (Phillips & Lancelotti 2014) and dental calculus (Power et al. 2015) have provided potential modern analogs for the study of early hominin diet and behavior.

The development of computer programs during this period introduced the use of technology in the morphometric analysis of phytoliths. Morphometric analysis relies on specific measurements of a phytolith such as length and width in order to classify phytoliths into taxonomic categories. Multiple taxa can produce phytoliths of the same morphotype, however, the size of the morphotypes can be taxonomically significant. Simple measurements of length and width can be made manually with the use of a microscope but complex measurements of size and shape can benefit from computer-assisted image analysis. This technology can reduce error within and between observers and allows for more rapid data collection (Welmoed et al. 2014). More information on the history of phytolith taxonomy is provided in Section 3.5 below.

Increased accessibility and utility of web-based resources has had an impact on the study of phytoliths. Several websites created in the past decade have searchable databases of phytolith images organized by taxon and region. Many of these sites are the result of independent comparative collection studies such as Phytoliths in the Flora of Ecuador (University of Missouri 2015). PhytCore is an online database of phytolith images searchable by archaeological site, taxonomic affiliation, or location within a plant. Such digital databases are useful, as they can alleviate the need for individual researchers to develop extensive comparative collections. Unfortunately, and for reasons unknown, several online phytolith image resources have appeared and disappeared in the past. Therefore, it is recommended researchers do not rely solely on web-based resources for reference materials (Hart 2016).

### **3.5 Phytolith Taxonomy**

Classification systems are required in order to divide phytoliths into distinct typological classes to aid in the identification and description of new and existing phytolith forms. Much work has been done in attempting to sort phytoliths into diagnostic groups or classes with varying results. This work has produced two contrasting perspectives on how to effectively classify phytoliths. Phytoliths are difficult to classify in any single way because they are both products of living plant species and therefore potentially subject to a Linnaean taxonomic system based on botanical characteristics but they are also inorganic particles that can be classified by a morphological, or non-taxonomic, system. Both systems have important strengths and weaknesses and both have been applied by to phytolith studies.

#### **3.5.1 Taxonomic vs. Non-Taxonomic Classification Schemes**

Ehrenberg's original classification scheme was based on the Linnaean taxonomic system, as he originally believed phytoliths to be the skeletons of some type of microorganism (Mulholland & Rapp 1992a). The strength of a taxonomic approach is the stress placed on correlating phytolith shapes with the plant species from which they were produced and with the evolutionary relationship of those species with other plant taxa (Piperno 1988). In a taxonomic system phytolith forms are named and categorized based on the morphological characteristics of the live plant tissues within which they are found. Examples of shapes named under this system include: trichomes, schlerids, and epidermal phytoliths. Metcalfe (1960) developed a taxonomic classification scheme based on his extensive research on the anatomy of the Gramineae (Poaceae). This system is preferable to botanists studying phytolith types because it provides information on the origins of phytoliths within plant tissues (Mulholland & Rapp 1992a, 1992b; Piperno 1988). Unfortunately, this method is not well-suited to the analysis of phytoliths found in sediments because they are not found in association with their surrounding plant tissues. This makes it very difficult to relate phytoliths from sediments to specific plant structures. Another downside of a strictly taxonomic approach is the presence of multiple phytolith morphologies within a single species and the redundancy of phytolith forms between taxa which makes it difficult to categorize phytoliths taxonomically (Mulholland & Rapp 1992a; Rovner 1971). Attempts have been made to resolve this problem using a parataxonomic approach, which allows phytoliths to be assigned into groups based on taxonomic relationships but also takes into

consideration morphological similarities between phytolith types when creating parataxa (Mulholland & Rapp 1992a). The downside of a parataxonomic approach is that it does not accurately reflect taxonomic relationships and does not recognize that certain phytoliths can be diagnostic to the genus or species level (Piperno 1988).

Non-taxonomic systems place an emphasis on morphological characteristics alone, placing phytoliths into discrete categories based on shape, size, and other visual features. Under a non-taxonomic system, phytoliths are named based on morphology. Examples of shapes named under this system include: dumbbell, trapezoid, or polyhedral. This type of system can accommodate the multiplicity and redundancy of phytoliths within and between species as such a system does not strive to associate specific morphologies with individual plant taxa. The main drawback of a non-taxonomic approach is that it is not well-suited to recognize where a certain phytolith type is formed within a particular plant body or species.

Both types of classification schemes have merits and the particular system chosen in any given research project is often based on the objectives of the research and the background of the researchers. For example, a non-taxonomic classification is better suited to identify isolated phytoliths extracted from sediments, while a taxonomic classification is better suited to identify phytoliths from living plant tissues (Mulholland & Rapp 1992b). Unfortunately, the existence of more than one scheme for phytolith classification has resulted in the use of different and multiple names for the same phytolith type. A lack of a standardized approach to naming has also resulted in an inconsistent body of literature with respect to phytolith identification (Dunn 1983; Fredlund & Tieszen 1994; Madella et al. 2005; Mulholland & Rapp 1992b).

As researchers independently develop phytolith classification systems on an individual basis, it is very difficult to cross-reference these systems (Bowdery et al. 2001; Piperno 2006). This problem was addressed in 2000 at the 3<sup>rd</sup> International Meeting on Phytolith Research, where a working group responsible for the development of an International Code for Phytolith Nomenclature (ICPN) was created. Madella, Alexandre, and Ball (2005) released the first ICPN which includes a standard protocol and glossary of descriptors for the identification and naming of phytolith types. The ICPN guidelines classify phytoliths first on their morphological (non-taxonomic) characteristics and then, if possible, a reference to the (taxonomic) association of a specific type is made (Madella et al. 2005).

### 3.5.2 Phytolith Taxonomy on the North American Plains

In the Great Plains region of North America the classification system proposed by Twiss et al. (1969) is one of the most widely accepted classification schemes for short-cell phytoliths in terrestrial sediments. This system is targeted to identify short-cell phytoliths from the leaves of three grass subfamilies that are dominant on the Northern Plains. This scheme emphasizes phytolith morphology when naming morphotypes (circular, cross, dumbbell, etc.) and divides these forms into four classes, three of which are diagnostic of certain grass subfamilies: Festucoideae (now Pooideae), Chloridoideae, and Panicoideae. The fourth Elongate class is represented by phytoliths that can be found in all grass species (Twiss et al. 1969). The Pooideae class is identified by the presence of circular, rectangular, elliptical, and elongate forms, the Chloridoid class is represented only by saddle-shaped forms, and the Panicoid class is represented by crosses, dumbbells, and crenate forms (Figure 3.1). This seminal work has been tested, and elaborated upon, by a number of independent phytolith researchers (e.g. Brown 1984; Fredlund & Tieszen 1994; Mulholland 1989).

Fredlund and Tieszen (1994) developed a classification scheme based on Twiss et al. (1969) and synthesized data from other existing classification schemes including Brown (1984), Mulholland (1989), and Mulholland and Rapp (1992). They identified ten morphological types representing three subfamilies (Pooideae, Chloridoideae, and Panicoideae) and one tribe (Stipeae). Keeled, conical, pyramidal, and crenate types are descriptive of Pooideae, while the Chloridoideae class is represented only by saddle forms. Panicoideae are identified by the presence of lobate, panicoid-type, and crosses. The Stipeae tribe is identified by the *Stipa*-type phytolith (Figure 3.2) (Fredlund & Tieszen 1994).

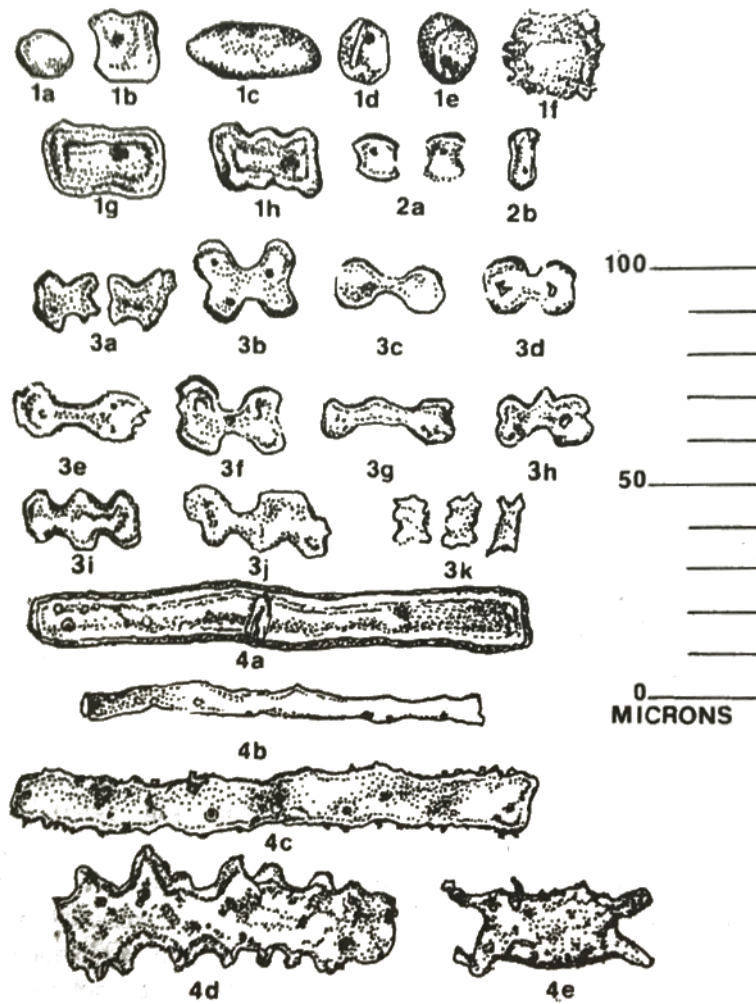


Figure 3.1: Grass short-cell phytolith classification after Twiss (1969:111 Figure 2). 1a-h Festuoid Class; 2a-b Chloridoid Class; 3a-k Panicoid Class; 4a-c Elongate Class (no subfamily characteristics).

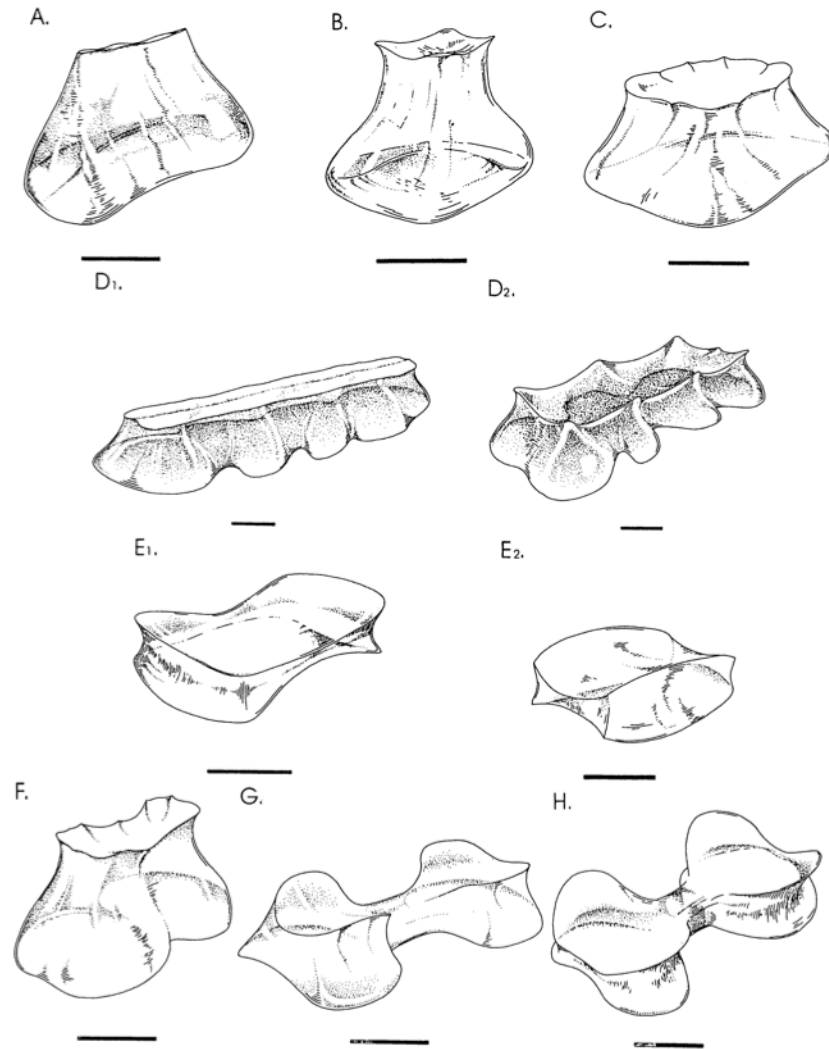


Figure 3.2: Typical Poaceae short-cell morphotypes A. Keeled, B. Conical, C. Pyramidal, D1 and D2. Crenate, E1 and E2. Saddle, F. Stipa-type, G. Simple Lobate, H. Panicoid-type. Scale bar represents 5 microns. After Fredlund and Tieszen (1994:326 Figure 2).

The Pooideae, Chloridoideae, and Panicoideae subfamilies are well-suited for phytolith analysis on the Northern Plains, as they are major contributors to Northern Plains vegetation and they exhibit different photosynthetic pathways. The Northern Plains are home to both  $C_3$  and  $C_4$  grasses, with  $C_3$  grasses most common in the eastern Tallgrass Prairie and  $C_4$  grasses more common in the western Shortgrass prairie. The Mixed-Grass Prairie includes both  $C_3$  tallgrasses and  $C_4$  short grasses (Redmann 2006). Pooideae is represented by  $C_3$  grasses, Chloridoideae are  $C_4$  grasses, and Panicoideae represent a mix of both  $C_3$  and  $C_4$  grasses. These different photosynthetic pathways represent different temperature and moisture requirements with  $C_3$  plants preferring a cool, moist environments, while  $C_4$  plants thrive in warm, arid conditions. The

identification of these three subfamilies pairs well with stable carbon isotope analysis as the C<sub>3</sub> and C<sub>4</sub> photosynthetic pathways can be identified through stable carbon isotopes.

Historically, most phytolith research has focused on grasses, however, distinct morphological differences exist between grass and arboreal and herbaceous dicot phytoliths. Wilding and Drees (1971) identified honeycomb, jigsaw, and plate-shaped phytoliths from modern arboreal species and terrestrial sediments from Ohio. Additional work on the identification of non-grass phytoliths has been undertaken on the Plains and surrounding Woodlands (Bozarth 1992, 1993; Geis 1973; Klein & Geis 1978; Norgren 1973). Polyhedral, jigsaw, and honeycomb phytoliths are produced in the leaves of most woody and herbaceous dicots with polyhedral types being the most common (Bozarth 1992). Perforated platelets are diagnostic of *Ambrosia psilostachya*, *A. trifida*, and *Xanthium strumarium*, all of which belong to the Asteraceae family, while segmented hairs are diagnostic of Asteraceae, Boraginaceae, and Cucurbitaceae (Bozarth 1992), all of which are found in Saskatchewan. Finally, the presence of bordered pits on silicified tracheary elements is considered to be diagnostic of the Pinaceae (Bozarth 1992).

The ability to distinguish between phytoliths produced from grasses and dicot species increases the value of phytoliths in the interpretation of paleoenvironments. Morphological analysis can provide identifications of species to the level of subfamily and in certain cases can reach genus or species-level identifications. The relative proportions of grass versus arboreal and shrub phytoliths can be used in paleoenvironmental reconstructions to make inferences on temperature and precipitation (Cyr et al. 2011; Dinan & Rowlett 1993).

### **3.6 The Utility of Phytoliths as a Proxy Environmental Indicator on the Northern Plains**

On the Northern Plains, a common goal of phytolith studies is to understand the timing and nature of Holocene climate change. It is known in a broad sense that the Northern Plains climate has shifted from periglacial conditions to a modern grassland environment. This is an oversimplification, as the shift to modern conditions throughout the Holocene was not linear, a number of climatic episodes occurred resulting in shifting environmental conditions over time. Of particular interest to paleoenvironmental studies is how those changes are reflected on a local and regional level. Phytoliths represent an opportunity to study vegetation changes over time on a local level (Piperno 1988:142; Rovner 1983). Despite the utility of phytoliths to serve as a proxy indicator of past vegetation change on the Northern Plains, few studies involving phytolith

analysis have been conducted in the region. This section includes a summary of the studies completed on the Northern Plains that include phytolith analysis. Radiocarbon dates are presented as radiocarbon years before present (BP), unless specified otherwise. Where applicable, calibrated dates are presented as cal. BP.

Analysis of phytoliths from the Cypress Hills region of Alberta has shown that vegetation composition in this region remained relatively constant throughout the Holocene. Phytolith records from the Alberta portion of the West Block of Cypress Hills Interprovincial Park date to a minimum of 9000 BP and span the Holocene to 500 BP (Klassen 2003; Robertson 2006). Phytoliths descriptive of the Pooideae subfamily are present in the highest concentrations consistently throughout the Holocene and indicate cool, moist environmental conditions. A decrease in arboreal phytoliths around 6730 BP suggests that Hypsithermal warming did have an impact on the Cypress Hills region, resulting in a shift from an arboreal to a grassland environment. It appears the warm, dry conditions of the Hypsithermal recorded elsewhere on the Northern Plains were not prevalent enough to cause a shift to C<sub>4</sub> vegetation, as C<sub>3</sub> vegetation remained dominant in the Cypress Hills (Robertson 2006). A decrease in the overall concentration of grass phytoliths after 5000 BP indicates a return to cooler, wetter conditions and an increase in arboreal vegetation for the remainder of the Holocene (Klassen 2003).

A paleoenvironmental analysis of the St. Louis Site, located near the town of St. Louis, Saskatchewan revealed a series of 21 paleosols dating to a minimum of 9150 <sup>14</sup>C yr. BP (Cyr et al. 2011). Analysis of the total concentrations of C<sub>3</sub> and C<sub>4</sub> grasses and arboreal phytoliths from the site revealed the consistent presence of a mixed grass prairie environment throughout most of the Holocene (Cyr et al. 2011). This shows that warmer and drier conditions existed at the St. Louis Site in the past, as the area is presently located in the parkland ecotone. Total phytolith concentrations coupled with an increase, but not dominance, of C<sub>4</sub> phytoliths around 6080 <sup>14</sup>C yr. BP indicate a vegetative response to Hypsithermal warming and drying. Post 6080 <sup>14</sup>C yr. BP conditions reflect a steady increase in C<sub>3</sub> grasses and arboreal phytolith concentrations, with a shift to dominance of arboreal phytoliths in the assemblage by 4590 <sup>14</sup>C yr. BP. These data suggest the vegetative cover at the St. Louis Site was approaching modern parkland conditions by this time. The uppermost paleosol at the site dates to 4590 <sup>14</sup>C yr. BP, so unfortunately little information is available for the late Holocene at this location (Cyr et al. 2011).



The Beacon Island site located in northwestern North Dakota revealed a profile dating back as far as 16 000 BP. Analysis of paleosol-derived grass short cell phytoliths was undertaken to identify periods of aridity during the Holocene. The results show a dominance of Pooideae phytoliths, indicating a mesic C<sub>3</sub> grassland prior to 10 300 BP. A gradual increase in *Stipa*-type phytoliths from 10 300-8000 BP indicates a trend towards a warm, dry environment during the early Holocene. A dominance of Chloridoideae forms by 8000 BP suggests a warm, dry climate existed in the area at this time. Post-8000 BP records indicate a gradual decrease in Chloridoideae and an increase in Pooideae phytoliths throughout the middle and late Holocene, reflecting a return to a mesic C<sub>3</sub> grassland similar to modern conditions (Mandel et al. 2014).

Phytoliths were extracted from a sediment core from the Red Tail Site located within Wanuskewin Heritage Park by Lauren Stead in 2013. Two radiocarbon dates were obtained from the top half of the sediment core. Only grass short-cell phytoliths were examined in this study and counts were low throughout the core. The data show a high concentration of Pooideae and *Stipa* phytoliths throughout the core, relative to a very low concentrations of Chloridoideae. Panicoideae phytoliths were notably absent from all samples. This suggests the prevalence of environmental conditions that support species favouring cool, moist conditions. Just prior to the radiocarbon date of 4000 BP a slight increase in Chloridoideae phytoliths was evident. Conditions returned to a dominance of Pooideae and Stipeae phytoliths soon after 4000 BP and remained stable through to modern times (Stead 2013).

Manitoba is mainly part of the Boreal Forest ecozone but a small section of the southwest corner is part of the Northern Plains. An analysis of phytoliths collected from three stratigraphic profiles in the Lauder Sandhills was undertaken in order to identify changes in vegetation during periods of landscape stability (Boyd 2005). Periods of stability were identified by the development of paleosols. Abundant grass phytoliths were recovered from several paleosols, while there was a marked absence of arboreal phytolith forms from all paleosols (Boyd 2005). Overall, the lowermost strata from the separate profiles were dated to 2500 <sup>14</sup>C yr. BP and were found to be Panicoid-dominant. An overall trend of a decrease in Panicoideae concentrations coupled with an increase of Chloridoideae phytoliths was observed from 2500 <sup>14</sup>C yr. BP to present. This sequence is interpreted as reflecting higher moisture levels at the base of the dune depression due to funneling of moisture downward toward the base of the depression around

2500  $^{14}\text{C}$  yr. BP (Boyd 2005). Over time, as the depression filled with sand, available moisture in the depression decreased, resulting in a succession to more dry-adapted species (Boyd 2005).

These studies show that phytolith analyses have been successfully applied to paleoenvironmental studies on the Northern Plains. The study by Stead (2013) in particular shows that phytoliths have been successfully recovered from Wanuskewin Heritage Park. The above studies show that the analysis of grass phytoliths from Northern Plains contexts can provide meaningful information on Holocene vegetative communities and provide opportunities to study vegetative responses to Holocene climate change.

### **3.7 Summary**

Phytoliths have a wide variety of potential applications for reconstructing past environments. They have the ability to identify past vegetation with reasonably high resolution. The ability of the analysis of these microscopic particles to aid in paleoenvironmental reconstruction in a variety of ways has made them subject to study by researchers all over the world. The ability of researchers to distinguish between different grass taxa based on phytolith morphology makes them particularly useful proxy indicators of paleoenvironments on the Northern Plains. Coupling data from grass phytoliths with that of dicots and arboreal species strengthens the utility of phytoliths in the documentation of transitional zones, particularly along the grassland/forest boundary of Saskatchewan.

## CHAPTER 4

### HOLOCENE CLIMATE CHANGE AND HUMAN-ENVIRONMENT INTERACTION ON THE NORTHERN PLAINS

#### 4.1 Introduction

Human responses to climate change on the Northern Plains during the Holocene is a subject of debate amongst archaeologists. While there is no doubt the past 10 000 years represented a change in climate from a glacial landscape to a grassland environment, this change was not linear and was punctuated by periods of heat and aridity followed by cool, moist conditions. The severity and duration of these changes and the extent to which they affected, or did not affect, human populations occupying the Northern Plains is of interest to archaeologists. It is difficult to specify the impact of Holocene climate change across the Northern Plains due to the size and physiographic diversity of the region (Vance et al. 1995). This chapter will focus on the existing climate data for southern Saskatchewan and explore current literature regarding human-environment interaction on the Northern Plains. Radiocarbon dates are presented as radiocarbon years before present (BP), unless specified otherwise. Where applicable, calibrated dates are presented as cal. BP.

#### 4.2 Regional Holocene Climate Change

Holocene climate records on the Northern Plains are often based on the interpretation of data obtained from lacustrine sediments. Closed-basin prairie lakes can be sensitive to changing environmental conditions which can directly influence lacustrine sedimentary characteristics (Fritz et al. 1991; Yansa 1998). Environmental changes can be inferred by the analysis of proxy indicators, which can include lake chemistry and mineralogy, salinity, water level records, diatoms, pollen, and macrofossils. A number of lacustrine sedimentary records have been studied from lakes in southern Alberta, Saskatchewan, and Manitoba. Table 4.1 presents a summary of the paleoenvironmental records inferred from the lacustrine sedimentary records included in this chapter. Figure 4.1 presents a map showing the location of these lakes.

Table 4.1: Summary of paleoenvironmental records used in this thesis (Laird et al. 2007; Last 1990; Last & Schweyen 1985; Last & Vance 2002; Last et al. 1998; Mott & Christiansen 1981; Ritchie 1976; Sauchyn & Sauchyn 1991; Vance et al. 1992; Vance et al. 1997; Yansa 1998, 2007)

Years BP	Chappice Lake	Harris Lake	Clearwater Lake	Martens Slough	Andrews Site	Waldsea Lake	Oro Lake	Ceylon Lake	Kenossee Lake	Russell Lake	Riding Mountain								
>11000			Freshwater lake, boreal forest	Open spruce forest	Freshwater, spruce forest		Freshwater lake				Spruce forest								
10500			Aspen parkland, peak salinity	Grassland conditions	Abundant charcoal, fires		High salinity			Spruce forest	Grassland								
10000										Populus grassland-shrub		High salinity	Grassland						
9500														Complete drying	Grassland				
9000																Water levels increase	Grassland		
8500																		Dry, saline, grassland, peak aridity	Grassland
8000																			
7500	Shallow, saline lake, grassland	Grassland																	
7000			Cool, moist conditions		Grassland														
6500							Ephemeral, saline lake, grassland-aspen parkland	Grassland											
6000										Dry, periods of moisture		Grassland							
5500											Open prairie, dry, warm conditions			Grassland					
5000	Saline lake												Grassland						
4500			Lake infilling, high salinity												Grassland				
4000				Fluctuating salinity & water levels		Grassland													
3500							Spruce, pine, birch, oak		Grassland										
3000										Increased spruce, pine, alder	Grassland								
2500	Modern vegetation - pine, birch, grasses, sage	Grassland																	
2000			Reduced salinity		Grassland														
1500				Salinity spike, low water levels				Grassland											
1000							Droughts					Grassland							
500														Grassland					

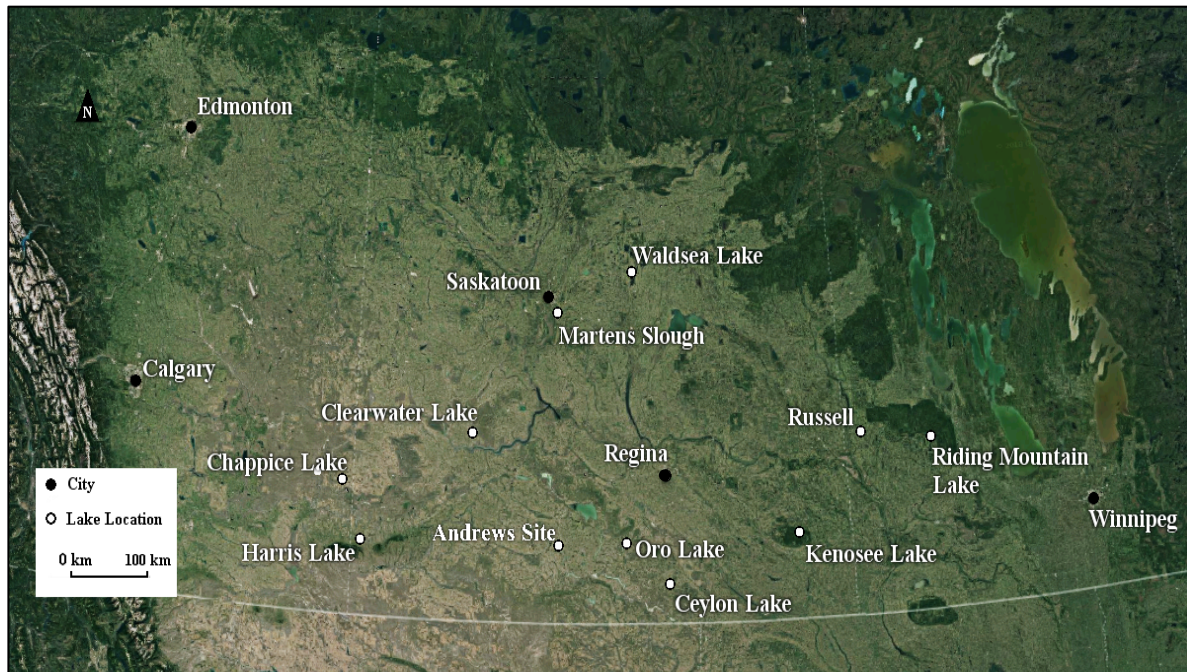


Figure 4.1: Lakes of the Northern Plains discussed in this chapter (GoogleEarth 2017, modified by author).

#### 4.2.1 Early Holocene (12 000-7000 BP)

The early Holocene was a period of rapid and dramatic climate change (Last & Vance 2002). As deglaciation occurred, glacial meltwater was funneled into meltwater channels and pooled in proglacial lakes, which are responsible for the origins of most extant lakes and river valleys within Saskatchewan (Vance et al. 1995). In Saskatchewan many kettle depressions, commonly known as prairie potholes or sloughs, formed by melting blocks of glacial ice buried by till, remain on the prairie landscape (Yansa 1998). A small number of these glacial lakes and kettle depressions in Saskatchewan have been studied, along with a few larger lakes of early Holocene origin, and serve as sources of Early Holocene climate data in Saskatchewan (e.g. Laird et al. 2007; Vance et al. 1995; Yansa 1998, 2007). Lacustrine sediment sequences extending to the Early Holocene are rare, as many of the lakes and kettle depressions are ephemeral or completely dried out at some point during the Holocene (Last 1990; Last et al. 1998; Vance et al. 1992).

Lacustrine records that exist for the Early Holocene indicate freshwater conditions prior to 10 000 BP. In most cases these freshwater lakes reflect glacial melt water (Laird et al. 2002; Last 1990; Last & Vance 2002). Post-10 000 BP, rapid changes in salinity within these lakes occur. At 9520 BP Oro Lake, SK (Figure 4.1; Table 4.1) becomes highly saline with peak

salinity occurring at 8650 BP with conditions remaining saline until the Late Holocene (Laird et al. 2007; Last & Vance 2002). Records from Clearwater Lake, SK (Figure 4.1; Table 4.1) indicate a shift from freshwater to saline conditions and a shift from Boreal Forest to open Parkland vegetation at 9800 BP. Peak salinity at Clearwater Lake is apparent from 9800-9600 BP with a second spike in salinity noted from 8000-7700 BP (Last et al. 1998).

Pollen records from lake sediments support the rapid Early Holocene climate changes. Pre-10 000 BP records analyzed by Ritchie (1976) suggest predominantly spruce forest conditions throughout southern Saskatchewan and in Manitoba at Riding Mountain Lake and Russell, MB (Figure 4.1; Table 4.1), with a sudden shift to grassland conditions at 10 500- 10 200 BP. Records from the Andrews Site, SK (Figure 4.1; Table 4.1) indicate a transition from spruce forest (>10 200 BP) to deciduous parkland (10 200-8900 BP) to open grassland (8800-7700 BP) (Yansa 1998, 2007). Data from Martens Slough (Figure 4.1; Table 4.1) in central Saskatchewan suggest a similar, though earlier transition from spruce forest (11 000 BP) to open spruce forest (10 500 BP) to open grassland (10 000 BP) (Mott & Christiansen 1981). At Harris Lake, SK (Figure 4.1; Table 4.1), a *Populus*-grassland-shrub environment is present at 9120 BP but by 7700 BP grassland species become dominant. Maximum aridity is apparent from 7700-6800 BP (Sauchyn & Sauchyn 1991). Lake sediments and pollen records indicate saline water conditions and grassland-dominated environments persisted at these locations until the end of the Early Holocene (Laird et al. 2002; Last et al. 1998; Mott & Christiansen 1981; Ritchie 1976; Yansa 1998).

#### **4.2.2 Middle Holocene (7000-5000 BP)**

The Middle Holocene climate is characterized by a period of increased temperature and aridity known as the Hypsithermal. Hot, dry conditions associated with the Hypsithermal resulted in decreased precipitation, salinization of lakes, reduction of streamflow, increased erosion and eolian activity, decreased vegetation cover and resource abundance, and an expansion of grasslands into adjacent ecoregions (Meltzer 1999; Vance et al. 1995). These changes are reflected in the Opimihaw Creek Valley as a reduction in stream flow which ended the incision phase of valley development (Burt 1997:168) and resulted in increased erosional and hillslope activity (Rutherford 2004:92). The time-transgressive nature of the Hypsithermal makes it difficult to define as different regions experienced the onset, maximum, and waning of the event at different times (Oetelaar 2011). For the western Plains, generally accepted dates range

from 9200-5900 BP (Vance et al. 1995) while on the eastern Plains 8500-4800 BP is the generally accepted range (Yansa 2007).

At Oro Lake peak salinity occurs at 8650 BP and salinity levels remain high until 5610 BP (Last & Vance 2002; Laird et al. 2007). A period of increased moisture is noted at 7400 BP which falls within the period of increased moisture conditions between 7700 and 6000 BP as reflected in proxy environmental indicators elsewhere on the Northern Plains (Yansa 2007). At Clearwater Lake, saline conditions continue through 7000 BP, at which time the lake may have dried out completely (Last et al. 1998). At Chappice Lake, SK (Figure 4.1; Table 4.1) grassland vegetation and maximum aridity occurred 7300-6000 BP, during which time a complete drying of the lake occurred. From 6000-4400 BP the lake was shallow and saline (Vance et al. 1992). At approximately 6000 BP, Ceylon Lake, SK (Figure 4.1; Table 4.1) experienced high salinity and very low water levels with several periods of complete desiccation from 6000-5000 BP. By 5000 BP, conditions became dominantly saline and remained so until present (Last 1990).

Pollen data from Harris Lake indicates dry, saline conditions and grassland vegetation from 7700-5000 BP with peak aridity 7700-6800 BP (Sauchyn & Sauchyn 1991). At Riding Mountain Lake, increased moisture conditions are inferred 6000-2000 BP by the presence of deciduous trees and reduced herb cover (Ritchie 1976). At the Andrews Site, maximum aridity is inferred by abundant charcoal, suggesting frequent fires from 8800-7700 BP (Yansa 1998). Increased water levels coupled with an increase in *Populus* suggests overall warmer conditions 7700-5800 BP (Yansa 1998).

#### **4.2.3 Late Holocene (5000 BP-present)**

The Late Holocene is characterized by a trend toward cooler, moister conditions. While overall the conditions of the Late Holocene are cooler and wetter than the Middle Holocene, fluctuations in temperature and moisture did occur. The Late Holocene can be divided into three main phases. The earliest phase is marked by cooler, moister conditions which are thought to have contributed to a worldwide Neoglacial advance that began 5000-2000 BP (Lamoureaux & Cockburn 2005:619) and the advance of alpine Rocky Mountain glaciers in North America (Mann 2002:504). The second phase, referred to as the Medieval Warm Period (MWP) or Medieval Climatic Optimum, dates to 1000-700 BP and is generally characterized by increased aridity visible in lacustrine paleoclimate records as decreased water levels and increased salinity indicating drought-like conditions during this time period (Grimm 2012; Vance et al. 1991). The

final phase, termed the Little Ice Age (LIA), lasted approximately 500-100 BP and is generally characterized by cool, moist conditions (Vance et al. 1991). While these trends are reflected in climate records throughout the region, not all episodes are present in all records and additional climate variation beyond the Neoglacial, MWP, and LIA are common on the Northern Plains.

Environmental conditions at Oro Lake 5000-3200 BP remained dry but were punctuated with prolonged periods of increased moisture (Laird et al. 2007). Conditions remained saline from 3200-1900 BP, with a reduction in overall salinity occurring at 1900 BP to present (Laird et al. 2007). At Harris Lake, cooler, moister conditions occurred from 5000-3200 BP as evidenced by an increase in *Pinus* and *Picea* pollen. Around 3200 BP a rapid return to a mosaic of mixed *Picea-Populus* forest and grassland conditions is noted and this vegetation continues to the present (Sauchyn & Sauchyn 1991). At Chappice Lake, low salinity and high water levels occurred from 2600-1000 BP. Long duration perennial droughts are evident from 1000-600 BP, which aligns with the Medieval Warm Period (Lemmen & Vance 1998; Vance et al. 1992).

At 4000 BP Waldsea Lake, SK (Figure 4.1; Table 4.1) was classified as a shallow ephemeral saline pool surrounded by mudflats and a grass-dominated Aspen Parkland (Last & Schweyen 1985). Fluctuating moist-dry conditions existed from 4000-3000 BP during which time a complete drying of the lake occurred. Dry, warm conditions are suggested from 2800-2000 BP, with an associated return to shallow mudflat conditions. The onset of cooler, moister conditions by 2000 BP is marked by a return to deep water conditions. Modern vegetation (pine, birch, grass, and sage) becomes established between 2000 BP to present and a final episode of increased dryness is indicated around 700 BP (Last & Schweyen 1985).

A multidisciplinary analysis of sediment cores from Kenosee Lake, SK (Figure 4.1; Table 4.1) provides a 4100-year record of the hydrological and climatic history of the lake and surrounding area. From 4100-3100 BP the lake was an open series of interconnected shallow, saline ponds. Rapid infilling occurred from 3000-2000 BP, resulting in a single, hyposaline lake, similar to conditions today. The lake experienced fluctuating water and salinity levels from 2300-2000 BP. An increase in salinity and decrease in the lake level over modern levels is apparent at 600 BP. Post-600 BP lake levels increased to peak levels and freshwater conditions (Vance et al. 1997).



### **4.3 Human-Environment Interaction on the Northern Plains**

#### **4.3.1 The Paleoindian Period (12 000-7500 BP)**

The earliest well-documented archaeological culture present in Saskatchewan is Clovis (11 050-10 800 BP) (Meyer et al. 2011; Peck 2011). Clovis peoples were highly mobile hunter-gatherers with a generalized foraging economy (Kelly & Todd 1988; Stanford 1999). Clovis hunters were reliant on large game including mammoth, bison, caribou, and elk, which were found in abundance on the Northern Plains (Grayson 1984).

Northern Plains environments in southern Saskatchewan shifted from spruce forest to open deciduous parkland prior to 10 500 BP (Mott & Christiansen 1981; Richie 1976). Deciduous trees replaced spruce trees along the shores of lakes and rivers, while grassland conditions remained in upland areas (Yansa 2007). The expansion of open forests into the Northern Plains likely allowed for the expansion of bison-hunting Folsom (10 900-10 200 BP) peoples to migrate northward into southern Saskatchewan (Hall 2009; Yansa 2007). This agrees with the interpretation of Folsom as bison hunters who followed the seasonal migration of herds (Meltzer 2004) but also took advantage of a variety of other subsistence resources (Dyck 1983; Stanford 1999).

The establishment of a productive mosaic-like open deciduous parkland/grassland supported abundant floral resources for humans and fauna (Yansa 2007). The variety of productive environments and the continued expansion of grasslands may help explain the emergence of numerous of Late Paleoindian groups on the Northern Plains (e.g. Folsom, Agate Basin/Hell Gap (10 500-9500 BP), Cody Complex (9500-9000 BP), Scottsbluff (8800-8400 BP), Eden (8800-8400 BP)) (Meyer et al. 2011; Yansa 2007). Despite the variety of available resources, these groups tended to focus on bison for subsistence. Faunal assemblages are dominated by bison remains and communal bison kill sites are common.

Evidence of increased warmth and aridity on the Northern Plains is evident as early as 9800 BP (Section 4.2.2). As groundwater sources began to dry due to glacial retreat and Hypsithermal warmth and aridity began to set in, groups were presented with new challenges in relation to resource procurement and access to freshwater sources. Late/Terminal Paleoindian groups (8500-7500 BP) began to diversify their diets to include a broader variety of plants and smaller game while still maintaining an emphasis on bison (Dyck & Morlan 2001; Rychlo 2016). Settlement patterns shifted to locations near permanent water courses such as major river

drainage systems, kettle lakes, perennial springs, and upland locations. These locations would have better supported a range of plant and faunal resources throughout the Hypsithermal (Buchner 1980; Yansa 2007). A restriction of available resources is suggested to have forced Plains peoples to diversify their diet to include smaller game, while simultaneously intensifying plant utilization (Frison 1975; Hurt 1966). It is worth noting here it has been hypothesized that the paucity of sites in other geomorphic contexts may relate to less favourable conditions for site preservation, as arid conditions can be less favourable to site preservation.

There is some disagreement as to the extent to which increased warmth and aridity affected bison populations. Data suggest increased dryness resulted in a northward shift of the boreal forest/aspen parkland/grassland ecotones (Zoltai & Vitt 1990) and the expansion of shortgrass prairie into the Northern Plains (Frison 1975; Reeves 1973). It has been suggested the reduced quality of forage would have decreased the size of bison populations and/or forced their migration into refugia (Frison 1975). Conversely, Reeves (1973) suggested bison populations may have increased as these animals are best adapted to grazing on shortgrass prairie. The record obtained from archaeological sites supports a continued focus on bison for subsistence with restricted geographic movement to areas less affected by Hypsithermal warming. This resulted in groups using a greater number of locally available resources (Dyck & Morlan 2011; Oetelaar 2011; Rychlo 2016), a trend which continued throughout the Early Middle Period (Rychlo 2016; Oetelaar 2011; Walker 1992).

#### **4.3.2 Early Middle Precontact Period (7500-5000 BP)**

Temporal and geographic variation of Hypsithermal conditions creates difficulty in assessing the level of impact this event may have had on human populations (Oetelaar 2011; Yansa 2007). Additionally, the severity of these changes appear to have varied locally (Section 4.2.2). It is evident that human responses to Hypsithermal climate change began during the Late/Terminal Paleoindian Period (8500-7500 BP) (Section 4.3.1) and those changes continued through the Early Middle Precontact Period (see below).

The earliest well documented Early Middle Precontact culture is that of Mummy Cave (7800-4500 BP), though relatively few Mummy Cave sites have been identified in Saskatchewan, most of which are clustered around major water sources (Walker 1992). Mummy Cave projectile points have been discovered at the Dog Child (FbNp-24) site at Wanuskewin and represent the earliest human occupation of the Opimihaw Creek Valley (Smith 2012).

Johnston (2005:21) argues the predominance of locally available stone for tool production, the high variability in projectile point styles, and the sparse, single component sites indicate a small Mummy Cave population on the Northern Plains. Bison remained the dominant food source in Mummy Cave occupations but the number of animals found at sites suggests small-scale hunting rather than mass-kill operations (Johnston 2005; Walker 1992). Highly processed faunal remains in association with anvil stones suggests intensive marrow extraction and grease production (Walker 1992:97). This, along with increased diversity in faunal assemblages compared with earlier and later periods, suggests a broad spectrum subsistence pattern (Johnston 2005:210-211). The settlement and subsistence patterns of Mummy Cave occupations fit with what would be expected for Late Paleoindian/Early Period adaptations to the Hypsithermal (Section 4.3.1). It is important to note that Early Middle period site numbers may be artificially low, due to the difficulty archaeologists may have in distinguishing Mummy Cave and other Early Middle period projectile points from the morphologically similar Besant points.

#### **4.3.3 Middle Middle Precontact Period (5000-3500 BP)**

The onset of the Middle Middle Precontact Period (5000-3500 BP) coincides with the appearance of Oxbow (5000-3800 BP) projectile points on the Northern Plains. This period also coincides with the onset of a cooling trend and increased moisture on the Northern Plains (Section 4.2.3). Oxbow toolkits are very similar to Mummy Cave and archaeologists distinguish between the two assemblages based on their diagnostic projectile points. At some sites, transitional Oxbow-Mummy Cave projectile points may exist (Dyck & Morlan 2001).

The analysis of Oxbow assemblages suggests a continuation of a broad spectrum subsistence strategy and opportunistic hunting of locally available small mammals, though a high frequency of bison bones recovered from Oxbow habitation sites suggests an emphasis on bison procurement. Curiously, currently there are no known bison kills that date to the Oxbow period in Saskatchewan (Nicholson & Webster 2011). Oxbow sites are clustered along major river valleys (Johnston 2005:31) and tend to be small, likely representing single family groups (Nicholson and Webster 2011). Oxbow lithic assemblages reflect predominantly local materials but some assemblages include Knife River Flint (Dyck 1983; Peck 2011). The presence of exotic items such as copper from the Great Lakes region and shell beads from the Atlantic coast suggests trade and increased mobility (Dyck & Morlan 2001; Nicholson & Webster 2011). Oxbow occupations have been recovered from several Wanuskewin sites (Section 2.4).

The rapid expansion of McKean (4200-3500 BP) hunter-foragers into the Northern Plains was facilitated by the use of major waterways like the Missouri and Saskatchewan Rivers (Webster 2004). While many McKean sites are located along major river valleys, sites on the Northern Plains are more closely associated with transitional environments which typically support a higher degree of biodiversity and resource stability (Webster 2004:77). Archaeological evidence supports the repeated use of sites in such locations by McKean peoples over centuries (Nicholson & Webster 2011). McKean occupations are generally small, suggesting small family groups (Webster 2004) similar to Oxbow occupations.

McKean peoples employed a subsistence strategy based on the exploitation of locally available resources. The faunal assemblages at McKean sites located in grassland environments tend to be dominated by bison, while sites on the fringes of Aspen Parkland and Boreal Forest environments tend to reflect a broader variety of subsistence resources (Webster 2004:73). The majority of known McKean sites on the Northern Plains represent the opportunistic hunting of one or two animals at a time (Webster 2004:75-76). McKean occupations have been recovered from several Wanuskewin sites (Section 2.4).

#### **4.3.4 Late Middle Precontact Period (3500-2000 BP)**

Pelican Lake (3600-2000 BP) hunters employed bison hunting strategies including pounds and jumps. Pelican Lake communal kill locations were used repeatedly by Pelican Lake hunters and by subsequent cultural groups (Dyck 1983; Reeves 1983). This increased reliance on bison over previous periods may be linked to expanding bison populations on the Northern Plains (Foor 1982), which may in turn be linked to the continuation of cooler, moister climate conditions (Section 4.2.3). While Pelican Lake hunters on the Plains focused on bison for subsistence (Reeves 1983), in the Foothills, where bison populations were smaller, they employed a broader subsistence foraging strategy (Duke 1986; Turnbull 1973).

The appearance of smaller Pelican Lake points may represent the initial adoption of the bow and arrow by Plains peoples (Dyck 1983). The use of the bow and arrow may have been beneficial in the hunting of smaller game, while more robust atlatl darts remained the more useful technology for communal hunting of large game (Kehoe 1974; Kevinsen 2013; Peck 2011).

The number of Pelican Lake sites on the Northern Plains is greater than the number of sites dating to each of the preceding cultures (Dyck & Morlan 2001). Pelican Lake sites are not

restricted to river terraces and are found on the open Plains (Reeves 1983). Foor (1982) suggests the distribution of Pelican Lake sites between open grassland and river valleys may reflect a seasonal round. Dyck and Morlan (2001) note that Pelican Lake sites “seem to be of a small, transitory, or task-specific type, and large base camps have not been found”. Reeves (1983) has linked the frequent use of communal bison hunting with larger populations in the grassland regions of the Northern Plains. This, in conjunction with an increased number of sites on the Northern Plains, suggests human populations may have increased during the Pelican Lake period. Though artifact assemblages indicate an emphasis on the use of local lithics (Reeves 1983) the inclusion of exotic lithics and trade items (Dyck & Morlan 2001; Reeves 1983) suggests interaction with adjacent groups (Nicholson & Webster 2011). Pelican Lake occupations have been recovered from several Wanuskewin sites (Section 2.4).

Increased archaeological visibility and inferred population increases climaxes with the Besant culture (2500-1400 BP) (Dyck 1983:113). It is important to note that Besant site numbers may be inflated by the difficulty archaeologists may have in distinguishing Besant projectile points from the morphologically similar Mummy Cave points (Walde et al. 1995). As with Pelican Lake, it is suggested the Besant focus on communal bison kills reflects large populations (Walde 2006). The intensification of communal kills produced large quantities of food for sharing and produced a surplus which could be stored for harsh winters or times of resource scarcity (Walde 2006).

Walde (2006:299, 304) outlines the social implications of the intensification of communal bison hunting during the Besant period. Increased complexity in the social and political organization of large populations is required to successfully carry out mass-kill operations. Further, Walde (2006:304) suggests the variability seen in tipi ring sizes during the Besant period may indicate increased social inequality, another indicator of social complexity, although he is careful to cite Vickers (1994) in noting increased tipi ring size is not sufficient on its own to denote social inequality. Besant occupations have been recovered from several Wanuskewin sites (Section 2.4).

#### **4.3.5 Late Precontact Period (2000-500 BP)**

Avonlea (1750-1150 BP) projectile points appear to be associated exclusively with bow and arrow technology (Peck 2011). This projectile point type has been recovered over a wide geographic range – from the Rocky Mountain Trench of British Columbia to western Manitoba

and from the Boreal Forest to southern Montana (Walde et al. 1995). Regional variants of the Avonlea culture are identified based on pottery types (Walde et al. 1995). This regionalization may account for some of the variance in Avonlea subsistence and settlement patterns, with Plains groups focusing on bison procurement and groups located on the fringes of the Plains adopting a broader subsistence pattern based on bison seasonal migration patterns. The decline of the Avonlea culture appears to coincide with the onset of the Medieval Warm Period (1000-700 BP). Avonlea occupations have been recovered from several Wanuskewin sites (Section 2.4).

People of the Old Women's Phase (1400-250 BP) were migratory bison hunters who occupied a variety of environments including open grasslands and parkland ecozones (Duke 1991; Vickers 1986). Oetalaar (2004) argues river valleys, streams, and coulees represent winter sites, while open prairie sites are ephemeral summer camps. The use of stones to anchor tipi dwellings on open prairie sites resulted in the high number of tipi ring sites common on the grasslands (Walde et al. 1995). Old Women's assemblages include Plains and Prairie Side-notched projectile points and Old Women's pottery. Several of the Wanuskewin sites have Old Women's Phase occupations (Section 2.4).

The Mortlach Aggregate (550-170 BP) represents a spatial and temporal range of components associated with Plains Side-notched points and Mortlach pottery (Schneider & Kinney 1978). These bison hunting peoples summered on the grasslands and made use of the parkland ecotone during the winter (Meyer & Epp 1990). Several different subphases of Mortlach have been identified based on pottery styles. It has been suggested this variety is related to Mortlach interaction with neighbouring cultures (Walde et al. 1995). Several Wanuskewin sites have Mortlach Aggregate occupations (Section 2.4).

#### **4.4 Summary**

This chapter provides a synthesis of paleoenvironmental data focused on the Northern Plains as well as a brief culture history of the region. The data presented here outline the timing and nature of climate and environment change and where possible relate those changes to human occupation in the region. It can be easier to make connections between cultural change and environmental influence during periods of more obvious climate change (i.e. the Hypsithermal) than over periods of more nuanced changes (i.e. the Late Holocene).

## CHAPTER 5

### PHYTOLITHS AND CARBON ISOTOPE ANALYSIS

#### 5.1 Introduction

Deposition of soluble silica begins in either the cell wall or cellular lumen of plant cells. As silica is deposited, the existing structures of the cell wall or cell lumen break down and are replaced with silica. Silicification of the cell wall traps a carbohydrate-rich matrix within the silica body. When the cellular lumen becomes silicified, a small portion of cytoplasm rich in lipids and proteins is trapped within the newly silicified cell (Hodson 2016; Hodson et al. 1984, 1985; Perry et al. 1987). This cellular material is embedded in the silica body and becomes occluded, or isolated, from the surrounding environment.

Jones and Beavers (1963) suggested cellular isotopic carbon trapped within phytoliths may provide an opportunity to determine  $^{14}\text{C}$  ages. This theory was tested by Wilding (1967), who obtained a radiocarbon age of  $13\,300 \pm 450$  BP from the carbon content of 60 g of phytoliths from Ohio soils. Isotopic carbon occluded within phytoliths has also been successfully applied to paleoenvironmental reconstructions using the  $\delta^{13}\text{C}$  value to assess the relative ratios of  $\text{C}_3$  to  $\text{C}_4$  plants within an assemblage (Kelly et al. 1991; Lu et al. 2000). This chapter will focus on the study of phytolith occluded carbon and its applications in radiocarbon dating and the assessment of  $\delta^{13}\text{C}$  ratios within phytolith assemblages.

#### 5.2 Applications in Radiocarbon Dating

Research into the utility of phytolith occluded carbon as a suitable candidate for carbon-14 dating is not a new phenomenon; it was first introduced during the 1960s (Jones & Beavers 1963; Wilding 1967). This research has benefitted immensely from modern technological advances. For example, in the 1960s Wilding (1967) had to process 45 kg of sediment to isolate the 60 g sample of phytoliths required for radiocarbon analysis. Thanks to the development of AMS dating, now only a 300 mg sample of phytoliths is required for a radiocarbon assay (Beta Analytic 2014).

It is important to note that dating the carbon within phytoliths does not produce the same type of date as a single object like bone or other organic material. While dating a single object of organic material from an archaeological occupation provides a single date that presumably relates to that specific occupation (aside from well-known problems such as dating old wood, intrusive material, or contaminated specimens), dates from phytoliths are the result of bulk sampling. Because of the bulk sampling nature of phytoliths, these dates represent an average date of production for the entire phytolith sample, which can vary depending on local deposition and sedimentation rates (Piperno 2006). In cases where adequate plant or faunal samples are available for dating discrete occupation events, radiocarbon dates from bulk phytolith samples can be less precise and therefore may not be a preferred option. Obtaining radiocarbon dates from bulk phytolith samples may prove useful in contexts that lack other datable materials or culturally diagnostic artifacts.

Studies assessing the utility of radiocarbon analysis of phytoliths in North America are few, and results have been inconsistent. Kelly et al. (1991) obtained radiocarbon dates from phytoliths taken from sites in Nebraska and Kansas and received mixed results. The Kansas site produced a radiocarbon chronology that increased in age with increasing soil depth, as expected. The Nebraska sites, however, produced radiocarbon chronologies that decreased in age with increasing soil depth. The authors suggest the radiocarbon reversal at the Nebraska sites was the result of bioturbation resulting in “new” or “young” phytoliths being translocated to deeper strata (Kelly et al. 1991). The lack of observed cases of vertical translocation of phytoliths within a sediment profile may call their explanation into question (Section 3.3).

In another case from North America, McClaren and Umlauf (2000) assessed the potential of obtaining radiocarbon ages from phytoliths and soil organic matter (SOM) from freshly excavated Arizona sediments. The results showed that phytolith radiocarbon dates were consistently older than those derived from SOM and the phytolith results showed two age reversals within the stratigraphic profile studied. The results of this study cannot be explained by bioturbation, as the SOM results did not reflect the same age-reversal.

There has been success obtaining radiocarbon dates from phytoliths in the Neotropics. Numerous studies from this region have produced radiocarbon ages from phytoliths that are internally consistent with dates derived from other materials (including bone, shell, and charcoal) from the same sites (e.g. McMichael et al. 2012; Piperno & Becker 1996; Piperno et al. 2000).



For example, the Las Vegas site, an important Early-Middle Holocene site in Ecuador, has a long series of radiocarbon dates from charcoal, shell, and human skeletons. This site provided an excellent sequence against which to compare radiocarbon ages from phytoliths. The results of this analysis showed a sequence of 10 phytolith radiocarbon ages in agreement with existing dates (Piperno & Stothert 2003).

Despite the success of Neotropical studies in producing sound phytolith radiocarbon assays, researchers elsewhere in the world have been unable to come up with successful results. In recent years, studies from France, Australia, and China have produced radiocarbon dates from phytoliths that are inexplicably old, ranging from a few hundred years to 20 000 years older than expected (Santos et al. 2010; Sullivan & Parr 2008; Yin et al. 2014). This has led to discussion among researchers as to whether radiocarbon analysis of phytoliths can in fact provide accurate dates (Piperno 2016). Rather than abandon this avenue of research altogether, attention has now been turned to discovering why these erroneous ages are occurring. Some hypotheses question the efficacy with which phytolith extraction methods can remove (or avoid introducing) extraneous carbon (e.g. Santos et al. 2010; Yin et al. 2014), while others suggest the source of carbon within the phytoliths themselves may be the issue (e.g. Santos et al. 2012).

The ability to which phytolith extraction procedures can remove, or avoid introducing, extraneous carbon is critical. Santos et al. (2010) raise the concern that certain organic solvents (e.g. ethanol, methanol, and acetone) used during the extraction procedure may bond to the surface of phytoliths and impact the radiocarbon results. In particular, North American produced ethanol may be a potential source of new carbon, as most ethanol in the United States is produced from corn (Santos et al. 2010). While the incorporation of carbon from such chemicals may result in unusually young dates, the unexpectedly young radiocarbon ages obtained by Kelly et al. (1991) cannot be explained by the use of ethanol, as they did not use it as a drying agent in their procedure.

Some authors (e.g. Kelly et al. 1991; McClaren & Umlauf 2000) suggest that a bath in  $\text{H}_2\text{O}_2$  may not be sufficient to remove SOM attached to phytoliths. As such, a stronger chemical reagent (e.g. nitric acid [ $\text{HNO}_3$ ], chloric acid [ $\text{HClO}_3$ ], potassium hydroxide [ $\text{KOH}$ ]) may be required to adequately remove SOM (Corbineau et al. 2013; Piperno 2006). At a minimum, a 6+ hour bath in  $\text{H}_2\text{O}_2$  is recommended to sufficiently remove organic matter from phytoliths. In a study of Papua New Guinea sediments, Boyd et al. (2001) showed phytolith extractions cleaned

with 30% H<sub>2</sub>O<sub>2</sub> produced radiocarbon ages that were younger than expected. When the samples underwent a strong acid treatment of chromic acid (H<sub>2</sub>CrO<sub>4</sub>) and were re-analyzed, the radiocarbon ages came back older, and matched the expected dates obtained from other sources. Interestingly, the successful phytolith radiocarbon results from the Neotropics were obtained using a combination of HNO<sub>3</sub> and HClO<sub>3</sub>, while H<sub>2</sub>O<sub>2</sub> was not used in the extraction process (Piperno 2006; Piperno & Stothert 2003; McMichael et al. 2012).

Some researchers argue the source of carbon within phytoliths themselves is the cause of extraneous radiocarbon dates. These researchers suggest the majority of carbon trapped within phytoliths originates from older SOM taken up via a plant's root system, rather than from atmospheric carbon absorbed via photosynthesis. As such, the older carbon from SOM results in older than expected radiocarbon dates (Santos et al. 2012). The problem with this hypothesis is it suggests plants are somehow preferentially selecting for carbon derived from SOM over carbon derived from the atmosphere via photosynthesis. As of yet, there is no evidence to suggest how or why plants would do this (Piperno 2016; Sullivan & Parr 2013).

Currently, there is no consensus as to the cause of erroneous radiocarbon ages obtained from phytolith samples. Based on the available evidence, it seems likely the cause of the problem lies with the removal of carbon from SOM bound to phytoliths during the extraction process. Results that match expected or existing radiocarbon dates have been obtained most frequently by researchers that use a strong acid or base (e.g. HNO<sub>3</sub>, HClO<sub>3</sub>, KOH, H<sub>2</sub>CrO<sub>4</sub>) during the extraction process. Further research involving the comparison of radiocarbon dates from sediments processed with H<sub>2</sub>O<sub>2</sub> versus sediments processed with a strong acid may aid in providing insight into this issue.

### 5.3 Applications in $\delta^{13}\text{C}$ Analysis

Carbon has two stable isotopes, <sup>13</sup>C and <sup>12</sup>C, and one radioactive isotope, <sup>14</sup>C. The stable isotopes are found naturally in atmospheric CO<sub>2</sub> in differing amounts with <sup>13</sup>C representing 1.1% and <sup>12</sup>C representing 98.9% of atmospheric carbon. The ratio between these isotopes is usually expressed in the form <sup>13</sup>C/<sup>12</sup>C. Plants absorb these isotopes in different amounts by preferentially metabolising <sup>12</sup>CO<sub>2</sub> over <sup>13</sup>CO<sub>2</sub> during photosynthesis (O'Leary 1988), a phenomenon referred to as isotopic fractionation. The ratio of <sup>13</sup>C/<sup>12</sup>C within organic materials is calculated using the formula:

$$\delta^{13}\text{C} = ((R_{\text{sample}}/R_{\text{standard}}) - 1) \times 1000$$

Due to the preferential selection of  $^{12}\text{C}$ , plants contain less  $^{13}\text{C}$  than is found in the atmosphere and  $\delta^{13}\text{C}$  values are represented as negative numbers. The extent to which plants discriminate against  $^{13}\text{C}$  during photosynthesis is related to the carbon fixation pathway, of which there are two main types – the Calvin-Benson ( $\text{C}_3$ ) or Hatch-Slack ( $\text{C}_4$ ) cycle.  $\text{C}_3$  plants are adapted to mesic (cool, moist) conditions and use the Calvin-Benson cycle to convert  $\text{CO}_2$  to sugars.  $\text{C}_3$  plants are common and include all trees and most shrubs and grasses from temperate and tropical areas (van der Merwe 1982). The Calvin-Benson cycle preferentially selects for  $^{12}\text{C}$ , which results in  $\text{C}_3$  plants exhibiting more negative  $\delta^{13}\text{C}$  values compared with atmospheric values (O’Leary 1988). Typical  $\delta^{13}\text{C}$  values of  $\text{C}_3$  plants vary between -35‰ to -20‰ with an average value of -27‰ (van der Merwe 1982).  $\text{C}_4$  plants are adapted to xeric (warmer, drier) conditions and use the Hatch-Slack cycle, which is more efficient at carbon absorption.  $\text{C}_4$  plants include some shrubs and grasses from arid regions of the world (van der Merwe 1982).  $\text{C}_4$  plants are more capable of converting both  $^{13}\text{C}$  and  $^{12}\text{C}$  to sugars, resulting in  $\delta^{13}\text{C}$  values that are less negative than atmospheric values (O’Leary 1988). Typical  $\delta^{13}\text{C}$  values of  $\text{C}_4$  plants vary between -16‰ to -9‰ with average values of -13‰ (van der Merwe 1982).

The very same carbon trapped within phytoliths that lends itself to  $^{14}\text{C}$  dating can be used to measure the  $\delta^{13}\text{C}$  of the plant during life. The  $\delta^{13}\text{C}$  value can provide information on the relative amounts of  $\text{C}_3$  and  $\text{C}_4$  plants present in an assemblage. This ratio is important because plants that use these different photosynthetic pathways tend to be found in different ecological settings and climatic zones. All tree species, most shrubs, and approximately half of grass species are  $\text{C}_3$ , while the remaining half of the grass species are  $\text{C}_4$  (Sage et al. 1999). Temperature and moisture are two major factors controlling the distribution of  $\text{C}_3$  and  $\text{C}_4$  grasses (Fredlund & Tieszen 1994, 1997; Teerie & Stowe 1976). The Poaceae family is represented by both  $\text{C}_3$  (372 genera) and  $\text{C}_4$  (428 genera) grasses (Sage et al. 1999). The Northern Plains are home to both  $\text{C}_3$  and  $\text{C}_4$  grasses, with  $\text{C}_3$  grasses most common in the eastern Tallgrass Prairie and  $\text{C}_4$  grasses more common in the western Shortgrass prairie (Redmann 2006). Currently, Wanuskewin Heritage Park lies within the Moist Mixed grassland ecozone of Saskatchewan, where both  $\text{C}_3$  tallgrasses and  $\text{C}_4$  short grasses are found, but it lies close to the southern boundary of the Aspen Parkland region (Section 2.5). The boundary of these ecozones is known to have shifted in the past (Section 4.2). Analysis of  $\delta^{13}\text{C}$  values from Wanuskewin Heritage Park has the potential to provide insight into past climatic conditions near a transition zone.

It was first demonstrated in the 1990s that  $\delta^{13}\text{C}$  values obtained from phytolith assemblages can reflect the  $\delta^{13}\text{C}$  values from modern plant specimens (Fredlund 1993; Kelly et al. 1991; Kelly et al. 1998). Using sediments from Nebraska sand dunes, Fredlund (1993) demonstrated the utility of the  $\delta^{13}\text{C}$  value of phytolith occluded carbon as a paleoenvironmental tool. This study compared the  $\delta^{13}\text{C}$  values of phytoliths from soil samples with the results of morphological analysis of phytoliths from the same samples. This study found the  $\delta^{13}\text{C}$  values correlated positively with the ratio of Chloridoid ( $\text{C}_4$ ) phytoliths; as the number of Chloridoid phytoliths in a sample increased, an increase in  $\delta^{13}\text{C}$  values was observed. This study also included analysis of isotopes of oxygen and hydrogen obtained from phytoliths. In combination, the results suggest paleosols formed during periods of increased moisture and increased temperature (Fredlund 1993).

Kelly et al. (1991) compared the  $\delta^{13}\text{C}$  values of phytoliths from soil samples with that of the standing vegetation at six virgin prairie sites. These sites were located along two different climatic gradients between North Dakota and the Colorado/Kansas border, one of decreasing precipitation, and one of increasing temperature, representing Short, Mixed, and Tallgrass Prairie environments. The results led the authors to conclude that the  $\delta^{13}\text{C}$  values from phytoliths correlated linearly with the  $\delta^{13}\text{C}$  values of the above-ground vegetation. The results also showed the phytolith  $\delta^{13}\text{C}$  values to be significantly depleted in  $^{13}\text{C}$  relative to that of the above-ground vegetation (Kelly et al. 1991). This phenomenon has been noted in several other studies involving the  $\delta^{13}\text{C}$  values of phytoliths.

Since these initial studies, a small number of subsequent studies comparing soil phytolith  $\delta^{13}\text{C}$  values with those from the modern standing vegetation and/or modern soil organic matter of the sample area have been undertaken (e.g. Lu et al. 2000; McClaren & Umlauf 2000; Smith & White 2004). Like the results obtained by Kelly et al. (1991) these studies noted a strong linear correlation between  $\delta^{13}\text{C}$  values from phytoliths and above-ground vegetation and a significant depletion of the  $\delta^{13}\text{C}$  value from phytoliths relative to that of the above-ground vegetation. In an analysis of sediments from various locations within the Central Plains, Smith and White (2004) found  $\delta^{13}\text{C}$  values from phytoliths are consistently more negative than values from modern soil or vegetation but note the values between the two maintain a strong linear correlation. By

analyzing the available literature, Smith and White (2004) discovered this was true regardless of the extraction method. The use of  $\text{H}_2\text{O}_2$  or a strong acid does not appear to affect the  $\delta^{13}\text{C}$  value.

Typical  $\delta^{13}\text{C}$  values for above-ground vegetation are -27‰ for  $\text{C}_3$  plants and -13‰ for  $\text{C}_4$  plants (van der Merwe 1982).  $\delta^{13}\text{C}$  values from phytoliths for  $\text{C}_3$  plants range between -34.4‰ to -25.5‰, with an average value of -29.2‰.  $\delta^{13}\text{C}$  values from phytoliths for  $\text{C}_4$  plants range between -25.7‰ to -15.1‰, with an average value of -21‰ (Smith & White 2004). The increased negativity of the phytolith  $\delta^{13}\text{C}$  scale has been suggested to be a result of the organic compounds contained within phytoliths themselves. During cell wall silicification, a small amount of cellular cytoplasm becomes trapped within the silicified cell. It has been hypothesized the depletions of  $\delta^{13}\text{C}$  values from phytoliths are the result of lipids trapped within phytoliths (Kelly et al. 1991), as lipids have depleted  $\delta^{13}\text{C}$  values relative to the whole plant (Collister et al. 1994). Smith and Anderson (2001) used tetramethylammonium hydroxide thermochemolysis and gas-chromatograph mass spectrometry to characterize the organic compounds contained within phytoliths. They found that phytoliths do contain lipids but do not contain other types of organic compounds that are found within plant tissues. The inclusion of lipids, which are typically depleted in  $^{13}\text{C}$ , and exclusion of other organic components would result in a comparatively low  $\delta^{13}\text{C}$  value for phytoliths. This explains why phytolith  $\delta^{13}\text{C}$  values are more negative than  $\delta^{13}\text{C}$  values from living plant tissues. Smith and Anderson (2001) also discovered that  $\text{C}_3$  and  $\text{C}_4$  phytoliths contain the same relative amounts of lipids, which does not explain why  $\text{C}_4$  phytoliths appear to have a proportionally more negative value with respect to living plant tissues. Smith and Anderson (2001) suggest  $\text{C}_3$  and  $\text{C}_4$  phytoliths may contain different proportions of polysaccharides such as cellulose and hemicellulose, which cannot be detected using tetramethylammonium hydroxide thermochemolysis and gas-chromatograph mass spectrometry. A further avenue of research is to evaluate the structural polysaccharide content of phytoliths to assess if differing proportions of these compounds are the cause of the compressed phytolith carbon isotope scale.

## 5.4 Summary

This chapter has outlined the utility of phytolith carbon isotope analysis. Carbon-containing cellular material trapped within phytoliths presents an opportunity for isotopic analysis. Radiocarbon dates from phytoliths can be used to provide dates from contexts that lack

diagnostic artifacts and other materials suitable for radiocarbon dating, though research indicates that there may be significant problems with the accuracy of phytolith-based radiocarbon dates. Analysis of  $\delta^{13}\text{C}$  values from phytoliths can provide insight into paleoenvironmental analyses by informing on the past ratio of  $\text{C}_3$  to  $\text{C}_4$  vegetation.

## CHAPTER 6

### MATERIALS AND METHODS

#### 6.1 Field Methods

Sediment samples were obtained in summer 2014 from profiles of six previously excavated archaeological sites within Wanuskewin Heritage Park. Backfill was removed using a backhoe and the edges of the previously excavated areas were located through the evaluation of elevation and differences between backfill and previously unexcavated deposits. As the wall of previous excavations were approached a shovel and subsequently a trowel was used to reveal the edge. Once revealed, the wall profiles were scraped clean with a trowel to reveal an uncontaminated surface. New stratigraphic profiles of the fresh walls were prepared and strata identified. Stratum thickness, sediment texture, colour, compaction, and inclusions (rocks, roots, charcoal, and artifacts) were recorded for each stratum. These profiles can be found in Section 7.3. At two sites (FbNp-1 and FbNp-25) pins from previous excavations marking cultural and stratigraphic levels were found in the wall profiles. This facilitated the correlation of the current sampling locations with the stratigraphic units as originally defined. Where previous pins were not discovered, strata were correlated based on depth and stratigraphy.

Sediment samples for paleoenvironmental analysis were taken from the fresh wall profiles. Where the thickness of the strata was less than 10 cm one sample was taken, for strata greater than 10 cm, samples were taken at 5 cm intervals. The depth and stratigraphic position were recorded for each sample and the sample locations were plotted on profiles.

#### 6.2 Laboratory Methods

##### 6.2.1 Sample Selection

A subset of 30 samples representing five samples from six archaeological sites were selected for phytolith analysis. Samples were chosen at random to include sediments from different contexts including presumed A horizons, alluvial, and colluvial contexts. This was done to test if phytolith concentrations at WHP can be used as an indicator of past landscape stability

and soil formation. This also served to test if processes of translocation have an impact on post-depositional movement of phytolith assemblages at Wanuskewin.

Currently, phytoliths are believed to be deposited by decay-in-place mechanisms and are relatively unaffected by post-depositional processes (Piperno 1988:142, Rovner 1983). Studies have shown phytoliths are a good indicator of soil A horizons (Jones et al. 1963; Jones et al. 1964) and that phytoliths appear in higher concentrations in soil A horizons compared to B and C horizons of the same sediment profile. In this way phytoliths can be used as an indicator, or “index mineral”, to identify times of past landscape stability and soil formation (Beavers & Stephen 1958).

The dominant site formation processes within WHP during the latter half of the Holocene are varied and include alluvial processes such as aggradation and lateral migration of the streambed and colluvial processes such as mass movements and slopewash (Section 2.2 and 2.3). Bioturbation, pedogenesis, and water percolation are also active processes within WHP. In order to ascertain that phytolith samples within WHP samples are unaffected or relatively unaffected by translocational processes and/or post-depositional movement, samples from a variety of depositional contexts were analyzed for the presence of phytoliths.

### **6.2.2 Phytolith Extraction Procedure**

A variety of methods exist for the extraction of phytoliths from sediment samples (e.g. Fredlund & Tieszen 1994; Lentfer & Boyd 1999; Madella et al. 1998; Piperno 2006). Most variation lies in the specific chemical reagents used and the ordering of steps. Certain sediment types such as those high in organic or clay content require additional steps and/or specific chemical reagents to maximize phytolith extraction. No single method is suitable for all sediment types; careful consideration must be taken before choosing the method that is right for any given project (Pearsall 2000:417; Piperno 2006:89). Important factors to assess include sediment characteristics, purity of extraction desired, budget, and capacity of the laboratory used to accommodate reagents of high toxicity.

The extraction procedure used for the current research was based on Zhao and Pearsall (1998), with some modification to suit the sediment characteristics, budget, and toxicity threshold. This method was chosen due to its applicability to a wide range of sediment types and suitability to soils with high clay and organic content (Zhao & Pearsall 1998). Modifications were based on methods used by Lentfer and Boyd (1998, 1999) and Piperno (2006).



Air-dried samples were manually disaggregated using a ceramic mortar and pestle and sieved through a 1.18 mm mesh screen (US Standard Geological Sieve #16) into a 500 mL beaker to remove large organic matter and large soil aggregates and clasts. The disaggregated sediment was weighed and 10.0 g was transferred into a 500 mL beaker, where 10.0 mL of reverse osmosis (R/O) water was added to the sample and allowed to soak for five minutes. The samples were transferred to 50 mL centrifuge tubes and centrifuged for two minutes at 2500 rpm and the supernatant containing light organic particles, such as rootlets, was decanted and discarded.

Reverse osmosis (R/O) water was chosen over distilled water because of the reduced cost. Powers and Gilbertson (1987) showed the use of filtered water over distilled water has no effect on the purity of the samples and no water-borne phytoliths are introduced to the sample using filtered water. Nevertheless, to ensure the purity of the samples processed as part of the current research, the R/O water was periodically checked for the presence of phytolith contaminants.

Some debate exists on how to proceed after manual disaggregation. Some methods proceed with organic removal followed by carbonate removal (e.g. Fredlund & Tieszen 1994; Lentfer & Boyd 1999; Piperno 2006:92). Zhao and Pearsall (1998) state that carbonate removal must be accomplished prior to organic removal if using hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) to digest organic material (as most researchers do, including Fredlund and Tieszen 1994; Lentfer and Boyd 1999; Piperno 2006:92), as  $\text{H}_2\text{O}_2$  performs poorly in an alkaline (carbonate) medium. This is especially important for the present study as the sediments are suspected to have a high carbonate content (Dr. Alec Aitken, personal communication 2015). For this reason, carbonate removal was performed prior to the removal of organic matter.

Carbonate removal was accomplished by washing the sample into a 500 mL beaker with a 1 M HCl solution and placing the beaker in a hot water bath. Samples rested in the hot water bath until the reaction weakened, at which time 1 M HCl was added in 10 mL increments. When no further reaction was generated upon the addition of fresh HCl, the reaction was considered complete and samples were removed from the heat and transferred into 50 mL centrifuge tubes. The samples were centrifuged for two minutes at 2500 rpm and the HCl decanted into containers for disposal. The samples were washed back into the 500 mL beakers with 1 M HCl and approximately 5 mL of concentrated stock HCl solution was added to the samples. Samples were

then placed in a hot water bath and stirred occasionally until the solution became clear. The exact time varied from approximately 30 minutes to two hours based on the carbonate content of the sample. When the solution was clear samples were transferred back into 50 mL centrifuge tubes and centrifuged for two minutes at 2500 rpm and decanted. Samples were then twice rinsed with R/O water, centrifuged for two minutes at 2500 rpm, and decanted.

The removal of organic matter as per Zhao and Pearsall (1998) involved a two-step process. The first step involved a bleach treatment where samples were washed into 500 mL beakers with household bleach and placed in a hot water bath for five minutes. This bleaching step acts as a “pre-soak” to aid in the removal of organic matter. This step must be performed carefully; if left for more than five minutes bleach can etch phytoliths (Zhao & Pearsall 1998). After bleaching, the samples were transferred back into 50 mL centrifuge tubes using R/O water, centrifuged for two minutes at 2500 rpm, and decanted. The samples were washed thoroughly with R/O water a minimum of two times to ensure complete removal of bleach, as bleach reacts violently with  $\text{H}_2\text{O}_2$  (Pearsall 2010:418).

The second step involved the oxidation of organic matter with  $\text{H}_2\text{O}_2$ . The samples were washed into 500 mL beakers using 30%  $\text{H}_2\text{O}_2$  and placed in a hot water bath where they were allowed to effervesce. As the reaction weakened, more 30%  $\text{H}_2\text{O}_2$  was added in 5 mL increments to keep the reaction going. Organic removal was considered complete when no reaction (i.e. bubbles) was produced upon the addition of new chemical. Some samples were very high in organic matter and took more than 24 hours for complete digestion. After 24 hours passed, stubborn samples were subject to a nitric acid ( $\text{HNO}_3$ ) treatment as per Piperno (2006:92) and Zhao and Pearsall (1998). Concentrated  $\text{HNO}_3$  is a strong acid that oxidizes organic material and aids in the removal of certain clay oxides. After organic oxidization was complete, the samples were transferred to 50 mL centrifuge tubes, centrifuged for two minutes at 2500 rpm and decanted, then washed twice with R/O water.

Next, phytoliths that may be bound to soil aggregates were dispersed. Typically, a sodium cation-based solution is used in phytolith extractions (e.g. Carbone 1977; Fredlund & Tieszen 1994; Madella et al. 1998; Rovner 1971). Zhao and Pearsall (1998) tested several commonly used dispersal agents for pH value and dispersion ability. It was found that some commonly used dispersal agents have a high pH value and could potentially dissolve phytoliths as a result. A 0.1%  $\text{Na}_2\text{H}_2\text{EDTA}$  solution was found to have a lower pH value and a high

dispersion ability. Based on the results of Zhao and Pearsall (1998) a 0.1% Na<sub>2</sub>H<sub>2</sub>EDTA solution was used as a dispersing agent in the current research. For the dispersion step samples were washed into 500 mL beakers with a 0.1% Na<sub>2</sub>H<sub>2</sub>EDTA solution. The beakers were filled to the 200 mL mark with 0.1% Na<sub>2</sub>H<sub>2</sub>EDTA and placed on a shaker at 350 rpm and left for at least 12 hours.

Once the sediments were dispersed and phytoliths were no longer potentially bound to clays, clay particles were removed from the sample. Clay removal traditionally takes place by gravity sedimentation using Stoke's Law for settling velocities. The downside of this method is time; to complete a single round of sedimentation it takes eight hours for clays to settle out of a 10 cm water column at 20°C using a specific gravity of 2.60 (Pearsall 2010:419-420) and multiple rounds are often required. Lentfer and Boyd (1999) documented that a centrifuge can be used to reduce the time required and remove clays as effectively as gravity sedimentation. For this reason, a centrifuge method opposed to the traditional gravity sedimentation method was used here.

After spending 12 hours on a shaker for dispersion the beakers were placed in a hot water bath and heated for 20 minutes. After which the samples were transferred to 50 mL centrifuge tubes, centrifuged for two minutes at 2000 rpm and decanted. The tubes were topped up to 50 mL with 0.1% Na<sub>2</sub>H<sub>2</sub>EDTA and this process was repeated until the supernatant was clear, indicating all clays had been removed.

The samples were separated into fine-silt (<20 µm), coarse-silt (50-20 µm), and sand (>50 µm) fractions after Piperno (2006:92). This step is optional and depends on the scope of the individual research project. First the sediments were sieved through 250 µm mesh into a 500 mL beaker to remove medium-sized and larger sand grains. Few phytoliths larger than 250 µm occur and those that do are from domesticated crops from the Near East (Rosen 1999) and therefore are not of relevance in Northern Plains prehistory. To separate the fine-grained sands from the silt the sediments were washed through a 53 µm mesh with a jet of R/O water. The portion caught in the sieve (fine-grained sand) was rinsed into a 50 mL centrifuge tube and set aside. The <53 µm fraction in the 500 mL beaker was further separated into a coarse-silt and fine-silt fraction by gravity sedimentation. R/O water was added to the beaker to a height of 5 cm, the solution was stirred vigorously, and then left to settle for two minutes and 20 seconds. The supernatant containing the fine-silt (<20 µm) fraction was poured off into another 500 mL beaker while the

50-20  $\mu\text{m}$  fraction was left settled in the bottom of the first beaker. This process was repeated until the supernatant was clear indicating the fine-silts had been fully extracted. All three fractions were concentrated into three separate 50 mL centrifuge tubes by centrifuging for two minutes at 2500 rpm and decanting the supernatant.

The next step involved extracting the phytoliths from the remaining sediment using heavy liquid floatation. A number of heavy liquids have been used effectively to extract phytoliths, including  $\text{CdI}_2/\text{KI}$  (Carbone 1977; Lentfer & Boyd 1998, 1999),  $\text{ZnBr}_2$  (Fredlund & Tieszen 1994), and sodium polytungstate (SPT) (Horrocks 2005; Madella et al. 1998). SPT was chosen for this research as it has been shown to produce a similar abundance of phytolith sizes compared with more toxic substances, along with its relatively inexpensive cost and low toxicity level (Zhao & Pearsall 1998). All three subsamples (fine-silt, coarse-silt, and sand fractions) for each of the processed samples were centrifuged for two minutes at 2500 rpm and decanted to remove water. To float the phytoliths 10 mL of a 2.3  $\text{g}/\text{cm}^3$  SPT solution was added to each subsample then stirred and centrifuged for five minutes at 3000 rpm. The supernatant containing the phytoliths was pipetted into clean 50 mL centrifuge tubes. The supernatant can simply be decanted off but experimentation during this research showed pipetting produced an extraction with fewer impurities. Approximately 30 mL of R/O water was added to the phytolith extracts to reduce the specific gravity of the solution to approximately 1.5  $\text{g}/\text{cm}^3$ . This was done to allow the phytoliths to sink to the bottom of the tube, as the specific gravity of phytoliths ranges from 1.5 to 2.3. The samples were stirred vigorously to mix the heavy liquid and R/O water and centrifuged for 10 minutes at 3000 rpm. At this stage the phytoliths exist as a fine white powder. The supernatant was decanted into a 1000 mL beaker and kept for recycling as heavy liquids are quite expensive but can be recycled efficiently (Pearsall 2010). This process was repeated until no visible material was seen floating in the heavy liquid. The phytolith extracts were then twice washed with R/O water and centrifuged for 10 minutes at 3000 rpm. Once washed, samples were transferred to ceramic crucibles and placed in a 100°C Precision® gravity convection oven to dry. After removal from the oven, dry weights of the extracts were recorded.

Samples were mounted on slides using the technique outlined by Pearsall (2010:445). A few drops of glycerol were applied to a clean, dry glass microscope slide. Next, 0.001 g of phytolith extract was weighed and sprinkled into the glycerol. A clean, dry probe was used to stir the phytolith extract into the glycerol and distribute it evenly within the matrix. A clean glass

coverslip was then applied to the slide and a clean probe was used to apply pressure to the coverslip to evenly distribute the mounted material.

### **6.2.3 Heavy Liquid Recycling**

The steps for recycling SPT were simple. The liquid was double-filtered, first through a 1 µm Whatman™ Microfiber Filter and second through a 0.45 µm Nalgene™ Analytical Filter. A double filtration system was used to increase the speed and efficiency at which the heavy liquid was filtered through the 0.45 µm filter. Larger particles tend to clog the 0.45 µm filter quickly, resulting in the need to constantly change the filters, which is costly.

## **6.3 Analytical Methods**

### **6.3.1 Phytolith Morphological Analysis**

The samples were analyzed using a Zeiss Axio microscope at magnifications of 400x and 630x. The identification of grass short-cell phytoliths was based on the classification scheme by Fredlund and Tieszen (1994) (see Section 3.5.2 for information on this classification scheme). While the extractions in this project almost certainly included non-short cell and non-grass morphotypes that could be identified to a particular genera, this was not attempted due to a lack of analyst expertise and appropriate comparative materials.

Phytoliths were counted by scanning the slides in horizontal transects until a count of 250 phytoliths was reached. If an entire slide was scanned before a count of 250 phytoliths was reached, a second, and in some cases a third slide was prepared to reach a combined total phytolith count of 250. In some samples, phytolith density was low and a total of 250 phytoliths was not reached after scanning three slides. There is some debate as to what number represents a sufficient count size to obtain statistically significant results in phytolith analysis (Stromberg 2009). Pearsall (2010) ran sample tests to determine the statistical reliability of phytolith counts and concluded that a count of 200 phytoliths was sufficient to return consistent results.

A selection of short-cell phytoliths were photographed using a microscope-mounted Canon EOS 70D camera. Photographs were taken at magnifications of 400x and 630x in order to capture the variation in size of short cell morphotypes. The photographs can be found as Appendix B. The grass short-cell phytolith counts were used to calculate the relative frequency of grass short-cell morphotypes within each sample.

## **6.3.2 Stable Carbon Isotope Analysis**

### **6.3.2.1 Radiocarbon dating**

A total of five phytolith samples from four archaeological sites were selected for radiocarbon analysis. Samples were selected based on four criteria – correlation with previously obtained radiocarbon dates, correlation with diagnostic projectile points, a sample count of 250 phytoliths, and overall purity of sample. Currently, there is some debate regarding the accuracy of radiocarbon dates obtained from phytoliths (Section 5.2). For this reason, correlation with previously obtained radiocarbon dates and diagnostic projectile points was necessary to test the accuracy of the radiocarbon dates obtained from the phytolith extraction procedure used in this thesis. A sample count of 250 phytoliths was required to ensure an adequate amount of phytolith carbon was present within the sample to obtain a radiocarbon date. Overall purity of the sample was considered to ensure radiocarbon dates were derived from phytolith carbon rather than carbon associated with the incomplete removal of organic matter or other sediments that were not removed during the extraction process. The samples were sent to Beta Analytic Radiocarbon Dating Laboratory in Miami, FL for AMS dating.

### **6.3.2.2 $\delta^{13}\text{C}$ analysis**

A total of 10 phytolith samples from five archaeological sites were selected for  $\delta^{13}\text{C}$  analysis. Samples were selected based on two criteria – a count of 250 phytoliths and overall purity of the sample. Overall purity of the sample was considered to ensure  $\delta^{13}\text{C}$  values were derived from phytolith carbon rather than carbon associated with the incomplete removal of organic matter or other sediments that were not removed during the extraction process. A sample count of 250 phytoliths was required to ensure an adequate amount of phytolith carbon was present within the sample to obtain a  $\delta^{13}\text{C}$  value. The samples were sent to G.G. Hatch Stable Isotope Laboratory at the University of Ottawa for analysis. Additionally, the five radiocarbon samples sent to Beta Analytic (Section 6.3.2.1.) were also subject to  $\delta^{13}\text{C}$  analysis, as Beta includes this type of analysis with AMS dating. In total, 15  $\delta^{13}\text{C}$  values were obtained and represent all six archaeological sites studied in this thesis.

## CHAPTER 7

### INTERPRETATION AND DISCUSSION

#### 7.1 Introduction

This chapter interprets the frequencies of grass short-cell phytoliths extracted from 30 sediment samples from six archaeological sites within Wanuskewin Heritage Park. Previous research has indicated relative frequencies of phytoliths are an accurate proxy for past vegetation (e.g. Fisher et al. 1995; Fredlund & Tieszen 1994; Kurmann 1985). On the Northern Plains, the analysis of grass short-cell phytoliths is particularly useful in interpreting past climate conditions (e.g. Fisher et al. 1995; Fredlund & Tieszen 1994, 1997). In this chapter, the results of the grass short-cell phytolith analyses are presented along with the results of  $\delta^{13}\text{C}$  and radiocarbon analyses of the phytolith samples studied for this project. Radiocarbon dates are presented as radiocarbon years before present (BP) unless specified otherwise. Where applicable, calibrated dates are presented as cal. BP.

#### 7.2 Interpretation of Phytolith Morphological Data

Multiple classification schemes exist for short-cell phytoliths on the Northern Plains, most of which are based on the original classification system proposed by Twiss et al. (1969). The classification scheme proposed by Fredlund and Tieszen (1994) represents a synthesis of existing classifications with a focus on the analysis of short-cell morphotypes produced within the grass family. This scheme was applied to the analysis of grass short-cell phytoliths in this thesis. This classification scheme identifies 10 morphological types that represent three grass subfamilies (Pooideae, Chloridoideae, and Panicoideae) and one genus (*Stipa*). For a discussion of current classification schemes for the Northern Plains see Section 3.5.2.

Within the Pooideae subfamily, keeled, conical, pyramidal, and crenate types are considered diagnostic forms (Fredlund & Tieszen 1994). These cool-season grasses exclusively use the  $\text{C}_3$  photosynthetic pathway, flourish in temperate latitudes, and are responsible for ~80% of the total grass flora on the Northern Plains (Twiss 1992). The keeled morphotype is associated with high production levels in *Pascopyrum smithii* (western wheatgrass) (Fredlund & Tieszen

1994; Mulholland 1989). This species prefers cool, temperate environments but is drought-tolerant and grows well in dry soils (Best et al. 1971; Budd et al. 1987; Leighton & Harms 2014). The conical morphotype is commonly produced by species of *Poa*, *Festuca*, and *Agropyron* (Fredlund & Tieszen 1994). The genus *Poa* is found in cool, temperate regions but is drought tolerant and grows well in dry soils (Best et al. 1971; Budd et al. 1987; Leighton & Harms 2014). The genus *Festuca* is commonly found in temperate prairie environments but thrives in dry prairie soils (Leighton & Harms 2014). The genus *Agropyron* is found in a variety of prairie habitats and can tolerate dry and moist soil conditions (Best et al. 1971; Budd et al. 1987). The pyramidal morphotype is commonly produced by many C<sub>3</sub> grasses of the Northern Plains (Fredlund & Tieszen 1994). The crenate morphotype is produced by a number of grasses within the Pooideae subfamily and is common in *Koeleria*, *Hordeum*, and *Elymus* (Mulholland 1989). The genus *Koeleria* is found in temperate grassland regions and is most commonly associated with dry soils (Budd et al. 1987; Leighton & Harms 2014). The genus *Hordeum* is common in dry prairie environments (Best et al. 1971; Budd et al. 1987; Leighton & Harms 2014). The genus *Elymus* in Saskatchewan is commonly found adjacent to rivers and marshlands in well-drained sandy soils (Best et al. 1971; Budd et al. 1987; Leighton & Harms 2014).

Within the Chloridoideae subfamily, saddle types are considered diagnostic (Fredlund & Tieszen 1994). Grasses of this subfamily exclusively use the C<sub>4</sub> photosynthetic pathway. These taxa favour warm, semiarid regions with low rainfall, or regions where rainfall occurs primarily in summer (Twiss 1992). They are commonly produced on the Northern Plains by shortgrasses, especially *Bouteloua* and *Buchloe*, which are dominant on the shortgrass prairies of the Northern Plains (Fredlund & Tieszen 1994). Chloridoid grasses are responsible for ~10% of the total grass flora on the Northern Plains (Twiss 1992). The genus *Bouteloua* is commonly found in dry prairie habitats (Best et al. 1971; Leighton & Harms 2014). The genus *Buchloe* is dominant in the dry, semi-arid shortgrass prairie regions of Saskatchewan (Leighton & Harms 2014).

Within the Panicoideae subfamily, lobate and cross types are considered diagnostic (Fredlund & Tieszen 1994). Approximately half of the species within this subfamily use the C<sub>3</sub> photosynthetic pathway and the other half the C<sub>4</sub> pathway. This taxa favours warm, humid environments and are commonly produced by Northern Plains tallgrass genera *Andropogon* and *Panicum* (Fredlund & Tieszen 1994). Panicoid grasses are responsible for ~10% of the total grass flora on the Northern Plains (Twiss 1992). The genus *Andropogon* is an important species



in the eastern tallgrass prairies of Saskatchewan (Best et al. 1971). The genus *Panicum* is found within warm, moist regions of the prairies (Best et al. 1971; Budd et al. 1987; Leighton & Harms 2014).

Within *Stipa*, the *Stipa*-type is considered diagnostic (Fredlund & Tieszen 1994). This genus is within the subfamily Pooideae and shares the characteristics of this taxon. This genus has recently been divided into three new genera – *Achnatherum*, *Nassella*, and *Hesperostipa* (Leighton & Harms 2014), all of which produce *Stipa*-type phytoliths. *Hesperostipa* is most common in Saskatchewan, growing in moist, temperate conditions but is commonly found in dry mixed grass regions (Leighton & Harms 2014).

Grasses that use the C<sub>3</sub> photosynthetic pathway are adapted to relatively cool, moist conditions while C<sub>4</sub> grasses thrive in relatively warm, arid conditions. As a result, C<sub>3</sub> and C<sub>4</sub> grasses tend to segregate along temperature and moisture gradients (Griffith et al. 2015). This phenomenon is visible on the Northern Plains, which are home to both C<sub>3</sub> and C<sub>4</sub> grasses. C<sub>4</sub> grasses are most common in the western Shortgrass prairie in the rain shadow of the Rocky Mountains. As moisture levels increase to the east, C<sub>3</sub> grasses become dominant in the eastern Tallgrass Prairie (Redmann 2006). The north-south temperature gradient of the Northern Plains also influences the distribution of C<sub>3</sub> and C<sub>4</sub> grasses, with heat-tolerant C<sub>4</sub> grasses decreasing in frequency towards the north, where C<sub>3</sub> grasses dominate the Mixed grass prairie region (Redmann 2006).

Temperature, followed by precipitation, is the strongest controlling factor of the relative abundance of C<sub>3</sub> and C<sub>4</sub> grasses (Griffith et al. 2015; Teeri & Stowe 1976; von Fischer et al. 2008). In particular, the average temperature and rainfall in July best explains the variation in the frequency of C<sub>4</sub> grasses where C<sub>4</sub> grasses are more abundant when the average July rainfall is high (von Fischer 2008). Mixed C<sub>3</sub> and C<sub>4</sub> grass systems persist on the Northern Plains when the mean July temperature is 22°C (Griffith et al. 2015; von Fischer et al. 2008). Seasonal competition can also have a significant effect on the relative proportion of C<sub>3</sub> and C<sub>4</sub> grasses. C<sub>3</sub> grasses can remain dominant throughout a hot summer if spring/fall conditions are cool (Tieszen et al. 1997). Conversely, C<sub>4</sub> grasses may not grow if temperatures are favourable for short time periods. The response of C<sub>4</sub> grasses to favourable growing conditions is high when just one month favours C<sub>4</sub> grasses (Griffith et al. 2015).

## 7.3 Interpretation of Phytolith Morphological Data and $\delta^{13}\text{C}$ Values by Site

### 7.3.1 Dog Child (FbNp-24)

The Dog Child site is located on a terrace with both alluvial and colluvial deposits. The terrace slopes to the east, dropping 10 m in elevation over approximately 100 m, before terminating in a steep bank which drops down to Opimihaw Creek (Burt 1997:134). Pins marking the cultural levels from previous excavations were not recovered during sediment collection. Figure 7.1 presents the relative frequency of short-cell morphotypes within each sample at FbNp-24. Figure 7.2 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths by depth at FbNp-24. Figure 7.3 represents the stratigraphic profile recorded during sediment sampling.

#### 7.3.1.1 FbNp-24-2

This sample was taken from a depth of 78-82 centimetres below surface (cmbs). A radiocarbon date from cultural level 3b above provides a minimum age of  $5003 \pm 45$  BP (Pletz 2010:298). This sample yielded very low overall phytolith numbers ( $n=3$ ). The depth of this sample is associated with a period of lateral migration of the stream channel or changes to the sediment load or discharge of the stream (Burt 1997:135-136). The depth of this sample is also associated with sediments low in organic carbon (Burt 1997:134-137). Coarse sand and small pebbles were noted in the sediment sample during the manual disaggregation phase. These data, in association with low phytolith yields, indicates this sample may be related to a period of landscape instability due to lateral migration or floodplain deposition.

It is worth noting this sample is associated with a minimum date that suggests an association with the end of the Hypsithermal. It is possible the low phytolith yield from this sample relates to extreme Hypsithermal conditions which may have resulted in very low vegetation growth rates. Based on the stratigraphic data associated with the sample and phytolith data from sites elsewhere in the valley that date to this period (Section 7.4), this is not likely the case. Due to low phytolith yields this sample was omitted from further paleoenvironmental interpretation.

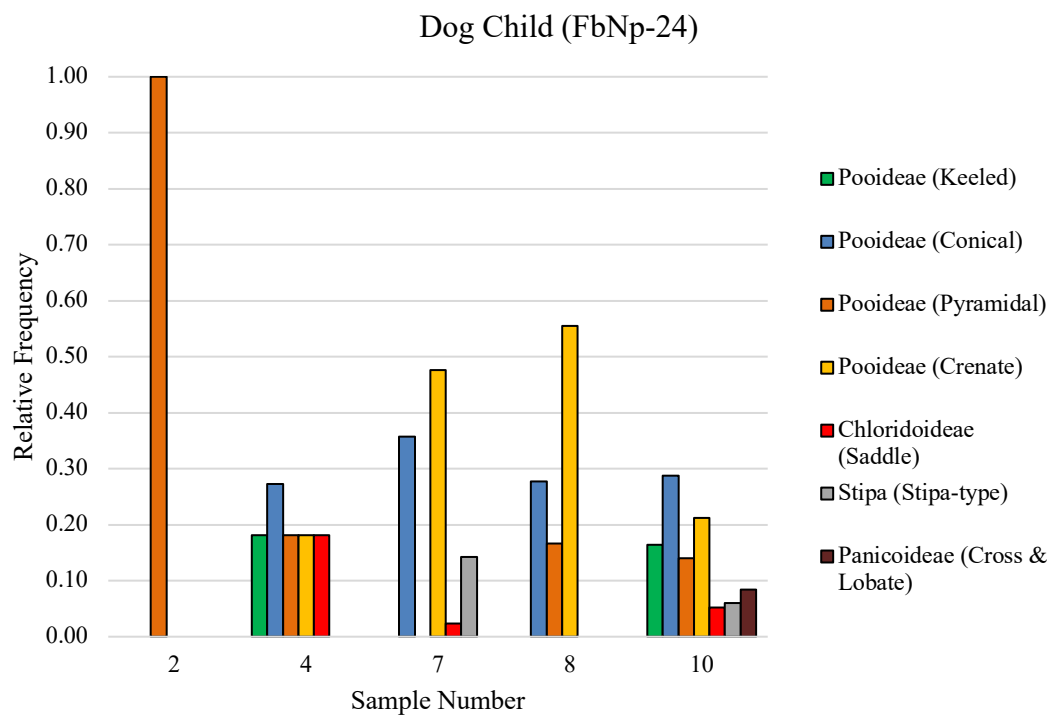


Figure 7.1: Relative frequency of short-cell phytoliths in samples from FbNp-24.

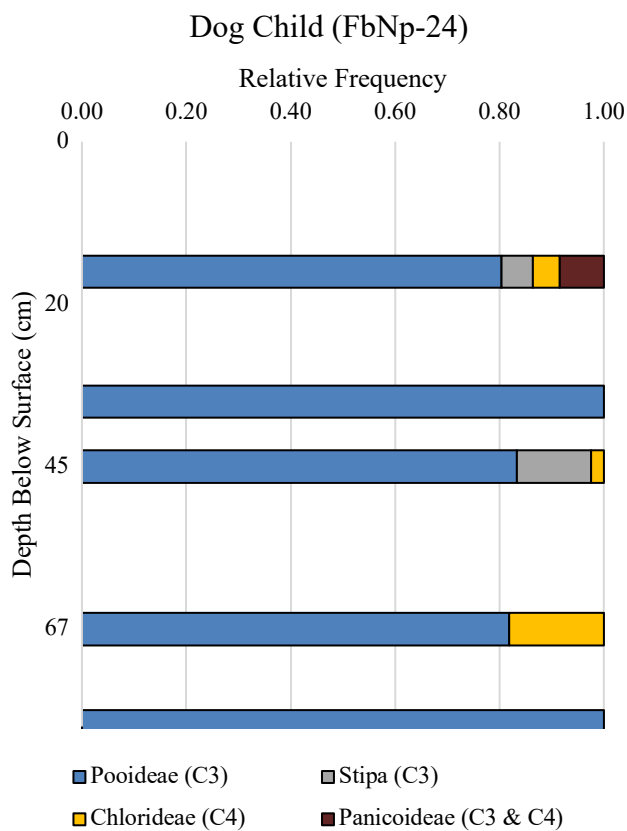


Figure 7.2: Relative frequency of short-cell phytoliths by taxa for FbNp-24.

### Profile of Dog Child (FbNp-24)

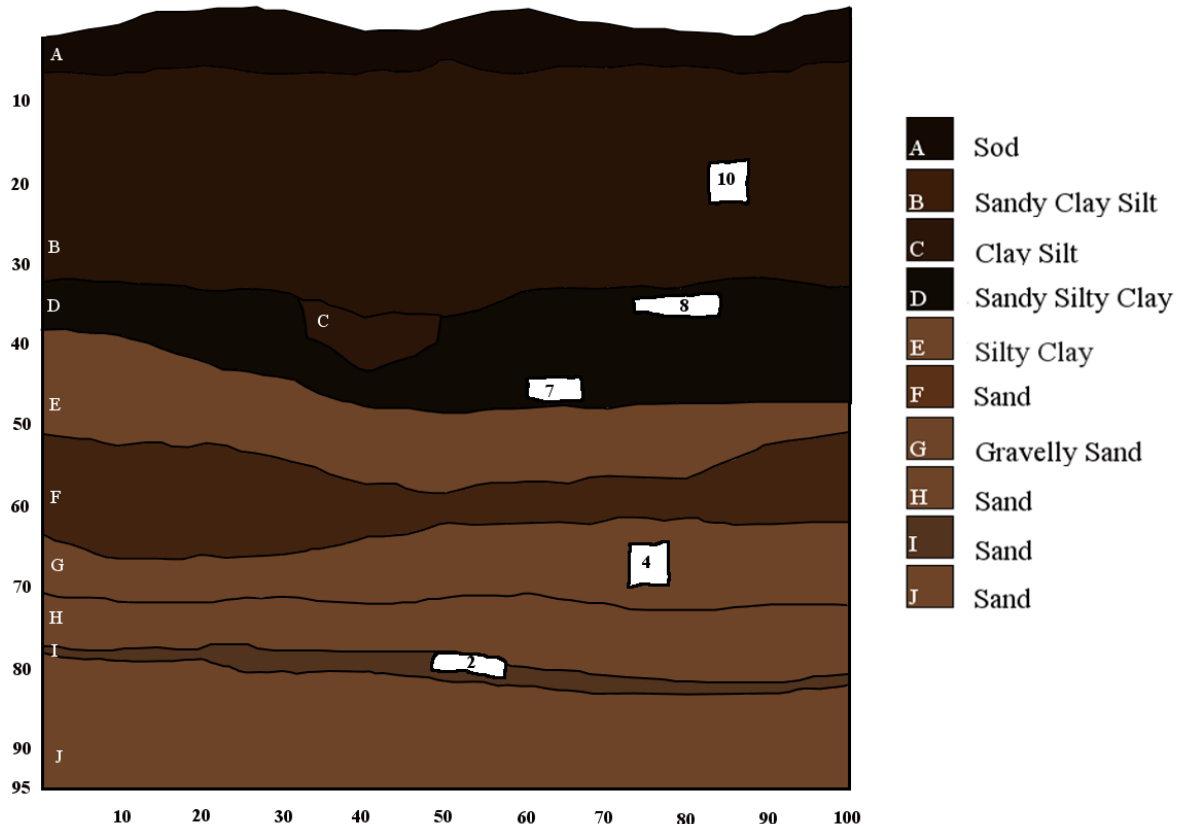


Figure 7.3: Wall profile of Dog Child (FbNp-24) showing phytolith sample locations. Axes are measured in centimetres.

#### 7.3.1.2 FbNp-24-4

This sample was taken from a depth of 65-70 cmbs and falls within the recorded depths for cultural level 3b (Pletz 2010:68-69). Cultural level 3b is associated with Gowen projectile points and radiocarbon dates of  $4780 \pm 50$  BP (Cyr 2006:29) and  $5003 \pm 45$  BP (Pletz 2010:298). In addition to a weak paleosol, cultural level 3b is associated with a lens of coarse sands and gravels (Pletz 2010:68). This sample yielded very low overall phytolith numbers ( $n=33$ ).

It is worth noting this sample is associated with a date range that suggests an association with the end of the Hypsithermal. Consequently, it is possible the low phytolith yield from this sample may relate to extreme terminal Hypsithermal conditions which may have resulted in very low vegetation growth rates. Based on the stratigraphic data associated with the sample and phytolith data from sites elsewhere in the valley that date to this period (Section 7.4), this is not likely the case. The depth of this sample is associated with a variable unit low in organic carbon which may be associated with lateral migration of the stream channel (Burt 1997:134-137).

Pebbles and gravels were noted in the sediment sample during the manual disaggregation phase which may suggest an association of this sample with the coarse sand and gravel lens present at this depth (Pletz 2010:68). These data, in addition to a low phytolith yield ( $n=33$ ), suggest this sample may be related to a period of landscape instability due to lateral migration of the stream channel. Due to low phytoliths yields this sample was omitted from further paleoenvironmental interpretation.

#### **7.3.1.3 FbNp-24-7**

This sample was taken from a depth of 44-47 cmbs and falls within the recorded depths for cultural level 3a (Pletz 2010:68). Cultural level 3a is associated with a transitional Mummy Cave/Oxbow occupation based on projectile points and radiocarbon dates of  $4597\pm50$  BP (Cyr 2006:29) and  $4168\pm40$  BP (Pletz 2010:297). Phytolith counts for this level were moderate ( $n=126$ ). The cultural materials from level 3a are associated with a weakly developed paleosol (Pletz 2010:67-68). It is likely sample FbNp-24-7 correlates with this weak paleosol. A weak paleosol may indicate reduced vegetation growth rates during this period, or may represent a short period of stability.

The phytolith morphological data for this sample suggest a dominance of Pooideae (83.3%) morphotypes, indicating cool to temperate conditions. Within the Pooideae, a dominance of crenate (47.6%) and conical (35.7%) morphotypes suggest cool temperatures and dry to moderate moisture conditions. The presence of Chloridoideae (2.4%) suggests warm temperatures and/or dryness. The genus *Stipa* (14.3%) suggests cool, wet conditions, however, this species also exhibits a high drought tolerance (Figure 7.1; Figure 7.2). Overall, temperature conditions were likely cool, while moisture conditions were likely dry to moderate.

#### **7.3.1.4 FbNp-24-8**

This sample was taken from a depth of 34-37 cmbs and falls within the depths recorded for cultural level 2b (Pletz 2010:68). Cultural level 2b is associated with Oxbow projectile points (Cyr 2006:92-98). Existing radiocarbon dates indicate an age of  $3938\pm40$  BP (Pletz 2010:296) and  $3867\pm50$  BP (Cyr 2006:191) for this level. This sample yielded low phytolith numbers ( $n=54$ ). The depth of this sample is associated with sandy, silty clay with a low organic content and is interpreted as representing a period of floodplain deposition and close proximity to the stream channel (Burt 1997:135-136). This sample likely correlates with a period of instability as a result of repeated floodplain deposition, resulting in low vegetation growth rates. It is likely the

low phytolith yield in this sample is an indication of landscape instability at this time. Due to low phytoliths yields this sample was omitted from further paleoenvironmental interpretation

#### **7.3.1.5 FbNp-24-10**

This sample was taken from a depth of 17-22 cmbs and lies between the recorded depths for cultural levels 1b and 2a (Pletz 2010:64-65). Radiocarbon dates from cultural levels 1b and 2a provide a maximum and minimum age for this sample of  $3460 \pm 45$  BP and  $241 \pm 50$  BP, respectively (Cyr 2006:29). The depth of this sample is associated with a cumulic soil which represents a long period of pedogenesis (Burt 1997:135). A radiocarbon date from bone obtained by Cyr (2006:191) suggest this cumulic soil horizon may have begun its development as early as  $3867 \pm 50$  BP. This sample yielded a high phytolith count ( $n \geq 250$ ), which may be another indication of a longer period of landscape stability.

The phytolith morphological data for this sample is interpreted as indicating a dominance of Pooideae (80.4%) morphotypes, suggesting cool to temperate conditions. Within the Pooideae, a high proportion of conical morphotypes (28.8%) suggests cool, dry conditions. Presence of the *Stipa* (6.0%) morphotype suggests cool, wet conditions, however, this taxon exhibits a high drought tolerance. High summer temperatures are implied by the elevated presence of Chloridoideae (5.2%). The presence of Panicoideae morphotypes (8.4%) indicates warm, moist conditions (Figure 7.1; Figure 7.2). Overall, cool spring/fall conditions with warm summer temperatures and summer rainfall are suggested.

A  $\delta^{13}\text{C}$  value of -27.7% (B1718-519-006) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, which suggests a dominance of  $\text{C}_3$  grasses (86.4%) (Figure 7.2).

#### **7.3.1.6 FbNp-24 Summary**

It is likely the terrace where Dog Child is located began as a colluvial slope which was later incised by the Opimihaw Creek (Burt 1997:137). The creek migrated eastward across the slope depositing alluvium as it migrated to its current location east of the terrace. These alluvial processes likely influenced the phytolith record at the site. Samples FbNp-24-2, FbNp-24-4, and FbNp-24-8 produced very low phytolith counts ( $n < 50$ ). This was likely due to the possible association of these samples with periods of alluvial deposition, lateral migration of the stream channel, and/or changes in sediment load or discharge resulting in reduced stability and periods

of low vegetation growth. The low phytolith counts ( $n < 100$ ) from these samples are likely indicative of landscape instability. The moderate count of phytoliths ( $n = 126$ ) along with stratigraphic information from FbNp-24-7 is likely indicative of an association with a weak paleosol. Sample FbNp-24-10 yielded a high phytolith count ( $n \geq 250$ ), and this sample is associated with sediments indicative of a well-developed paleosol. These samples suggest that phytolith counts at FbNp-24 can be used as an indicator of past landscape (in)stability.

The time period represented by sample FbNp-24-10 could not be narrowed down further and represents a potential age range based on existing limiting radiocarbon dates of  $241 \pm 50$  to  $3460 \pm 45$  BP. This extended time range is less useful than shorter time ranges when attempting to correlate climate data from this site with regional changes throughout the Late Holocene. For this reason, sample FbNp-24-10 was not included in the discussion of broader climatic trends in Section 7.4 below. Due to their low phytolith yields ( $n < 100$ ), samples FbNp-24-2, FbNp-24-4, and FbNp-24-8 were also excluded from paleoenvironmental interpretation. The counts for sample FbNp-24-7 are moderate and this sample is discussed in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

### **7.3.2 Thundercloud (FbNp-25)**

The Thundercloud site is located on an alluvial terrace where the geomorphology is dominated by fluvial processes. Pins marking two of the cultural levels identified during previous excavations were recovered during sediment sampling (Figure 7.6). This facilitated the correlation of samples FbNp-25-2, FbNp-25-3, and FbNp-25-4 with known cultural occupations at the site. Figure 7.4 presents the relative frequency of short-cell morphotypes within each sample at FbNp-25. Figure 7.5 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths by depth at FbNp-25. Figure 7.6 represents the stratigraphic profile recorded during sediment sampling.

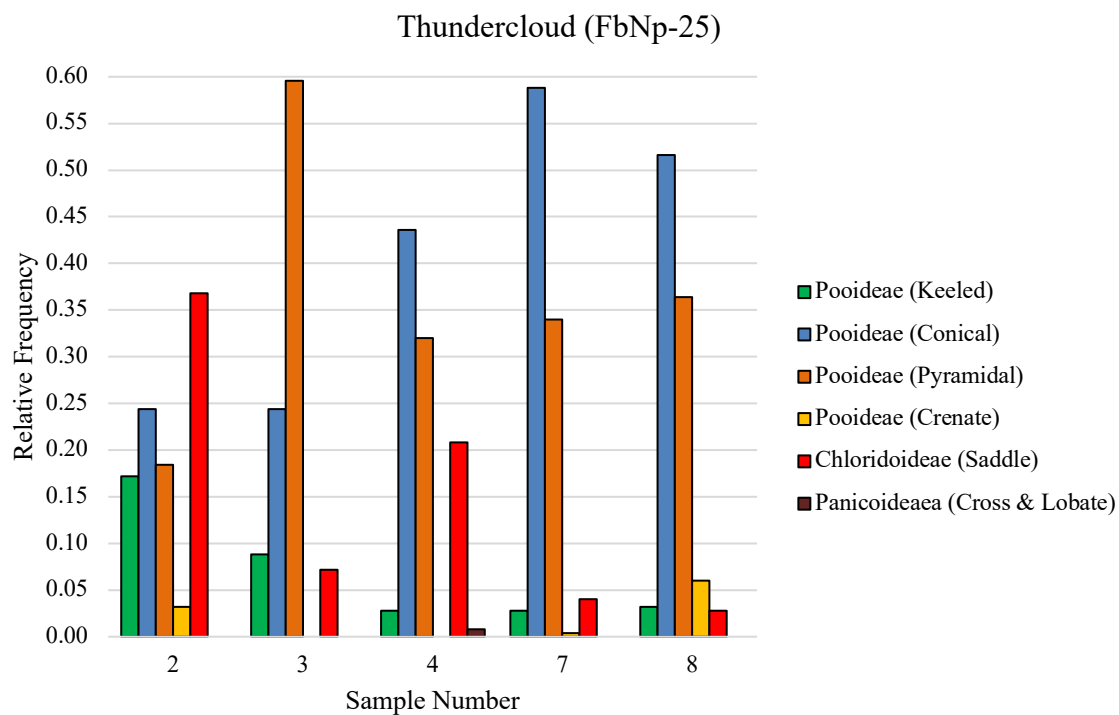


Figure 7.4: Relative frequency of short-cell phytoliths in samples from FbNp-25.

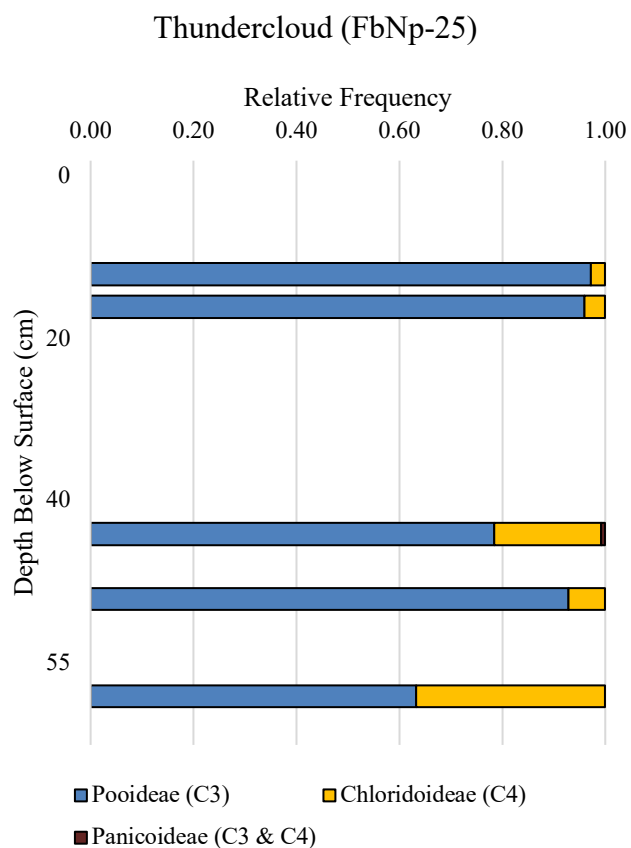


Figure 7.5: Relative frequency of short-cell phytoliths by taxa for FbNp-25.



Profile of Thundercloud (FbNp-25)

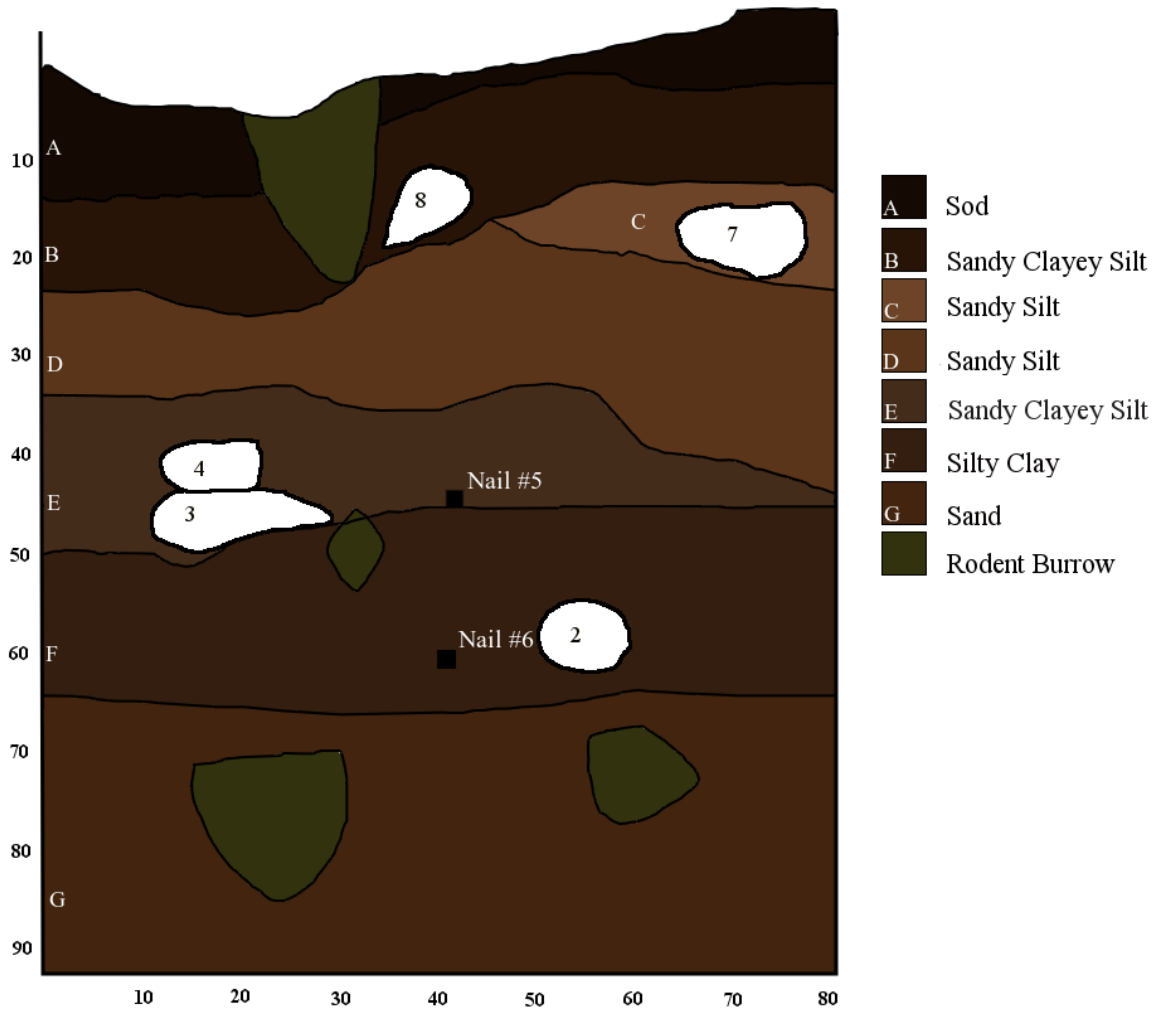


Figure 7.6: Wall profile of Thundercloud (FbNp-25) showing phytolith sample locations. Axes are measured in centimetres.

### 7.3.2.1 FbNp-25-2

This sample was taken from a depth of 58-63 cmbs. Stratigraphic association with pin #6 from previous archaeological investigations suggests this sample is associated with cultural level 6 (Figure 7.6). The recovery of two Oxbow projectile points from depths of 50.5 cmbs and 65.6 cmbs may indicate this sample is of Oxbow age (5000-3800 BP) (Mack 2000:211). A radiocarbon date from cultural level 5 above suggests a minimum age of  $4040 \pm 90$  BP. A count of 250 phytoliths was reached for this sample.

Burt (1997:129) identified organic staining and increased organic content in this stratum which she has identified as a cumulic regosol (Burt 1997:131). Archaeological excavations also identified cultural level 6 within a paleosol (Webster 1999:30). These observations, in

association with a high phytolith count ( $n \geq 250$ ), suggest this stratum likely relates to a period of extended landscape stability and pedogenesis.

The phytolith morphological data for this sample indicate a dominance of Pooideae (63.2%) morphotypes, suggesting cool, temperate conditions. The total frequency of Pooideae morphotypes makes up the majority of the assemblage, however, Chloridoideae (38.8%) is the dominant individual morphotype. This suggests that conditions were much warmer and drier than is suggested by any other sample at this site (Figure 7.4; Figure 7.5). Overall, the phytolith assemblage at this site is interpreted as indicating cool to moderate spring/fall temperatures and warm and dry summer conditions.

#### **7.3.2.2 FbNp-25-3**

This sample was taken from a depth of 45-48 cmbs and falls within the depth ranges recorded for cultural levels 5 and 6 (Webster 1999:26-27). Stratigraphic association with pin #5 from previous archaeological excavations suggests this sample is associated with cultural level 5 (Figure 7.6). Cultural level 5 is associated with McKean series projectile points and radiocarbon dates of  $4040 \pm 90$  BP,  $3315 \pm 50$  BP, and  $3150 \pm 50$  BP (Webster 2004:34-35). A count of 250 phytoliths was reached for this sample.

Burt (1997:129) identified increased organic content in the sediments related to cultural level 5 and suggests this stratum is associated with a cumelic regosol (Burt 1997:131). Archaeological excavations also identified cultural level 5 within a paleosol (Webster 1999:30). These observations, in association with a high phytolith count ( $n \geq 250$ ), suggest this stratum likely relates to a period of extended landscape stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (92.8%) morphotypes, suggesting cool, temperate conditions. Within the Pooideae, a slight decrease in keeled (8.8%) morphotypes over the above sample suggests a slight decrease in drought-tolerant species. The dominance of the pyramidal (59.6%) morphotype provides little paleoenvironmental value, as grasses that produce the pyramidal type live in a broad variety of habitats from wet to dry areas. A relatively high proportion of Chloridoideae (7.2%) suggests warm temperatures and dry conditions, although not as high as FbNp-24-2 below and FbNp-25-4 above (Figure 7.4; Figure 7.5). Overall, this sample likely represents cool to warm spring/fall conditions with slightly warm summer temperatures.

A  $\delta^{13}\text{C}$  measurement of -26.4‰ (B1718-519-007) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (92.8%) (Figure 7.5).

#### **7.3.2.3 FbNp-25-4**

This sample was taken from a depth of 40-45 cmbs and falls within the depth range recorded for cultural level 5 (Webster 1999:26-27). Stratigraphic association with pin #5 from previous archaeological excavations (Figure 7.6) further evidences the association of this sample with cultural level 5. Cultural level 5 is associated with McKean series projectile points and radiocarbon dates of  $4040 \pm 90$  BP,  $3315 \pm 50$  BP, and  $3150 \pm 50$  BP (Webster 2004:35). A count of 250 phytoliths was reached for this sample.

Burt (1997:129) identified increased organic content in the sediments related to cultural level 5 and suggests this stratum is associated with a cumulic regosol (Burt 1997:131). Archaeological excavations also identified cultural level 5 within a paleosol (Webster 1999:30). These observations, in association with a high phytolith count ( $n \geq 250$ ), suggest this stratum likely relates to a period of extended landscape stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (78.4%) morphotypes, suggesting cool, temperate conditions. Within the Pooideae, a high proportion of the conical morphotype (43.6%) suggests cool, dry conditions. A high proportion of Chloridoideae (20.8%) suggests high temperatures and decreased moisture conditions, though not as high as FbNp-25-2 (Figure 7.4; Figure 7.5). Overall, this sample likely represents cool, spring/fall conditions and warm, dry summers.

A  $\delta^{13}\text{C}$  measurement of -27.6‰ (B1718-519-008) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (78.4%) (Figure 7.5). Together, these data show that despite the high proportion of Chloridoideae (20.8%) in this sample, conditions were not sufficiently warm and dry to result in a shift from a  $\text{C}_3$ -dominant to a  $\text{C}_4$ -dominant environment.

#### **7.3.2.4 FbNp-25-7**

This sample was taken from a depth of 15-22 cmbs and falls within the depth range recorded for cultural level 3 (Webster 1999:26). Cultural level 3 is associated with Avonlea and

Besant projectile points, suggesting an age of ca. 2500-1050 BP (Webster 1999:26). A count of 250 phytoliths was reached for this sample.

Burt (1997:131) identified cultural level 3 within a thick, organic-rich unit associated with a cumulic regosol. Archaeological investigations also associate cultural level 3 with a thick buried soil horizon (Webster 1999:26-27). These data, in association with a high phytolith count ( $n \geq 250$ ), suggest this stratum likely relates to a period of extended landscape stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (96.0%) morphotypes, suggesting cool, temperate conditions. Within the Pooideae, a low abundance of the crenate (0.4%) morphotype may indicate warm overall temperatures. The presence of Chloridoideae (4.0%) may indicate warm temperatures and dry moisture conditions in the summer months (Figure 7.4; Figure 7.5). This sample is interpreted as indicating temperate conditions with some dryness throughout the summer.

A  $\delta^{13}\text{C}$  measurement of -25.9‰ (B1718-519-009) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (96.0%) (Figure 7.5).

#### **7.3.2.5 FbNp-25-8**

This sample was taken from a depth of 12-19 cmbs and overlaps with depths recorded for both cultural levels 2 and 3 (Webster 1999:25). A minimum date associated with a Mortlach occupation (ca. 550-170 BP) is provided from cultural level 2 and a maximum date associated with a Besant occupation (ca. 2500-1400 BP) is provided from cultural level 3 (Webster 1999:25-26). A count of 250 phytoliths was reached for this sample.

Archaeological excavations associate the cultural materials from levels 2 and 3 with a thick buried soil horizon (Webster 1999:26-27). Burt (1997:131) also identified cultural levels 2 and 3 within a thick, organic-rich unit and identified this stratum as a cumulic regosol. These data, in association with a high phytolith count ( $n \geq 250$ ), suggest this stratum likely relates to a period of extended landscape stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (97.2%) morphotypes, suggesting overall cool, temperate conditions. The presence of Chloridoideae (2.8%) suggests warm temperatures and decreased rainfall likely in July. Many

Pooideae species are drought and heat resistant and can tolerate higher temperatures and decreased moisture conditions (Figure 7.4; Figure 7.5). This sample likely reflects overall cool, temperate conditions with some dryness throughout the summer.

A  $\delta^{13}\text{C}$  measurement of -28.4‰ (B1718-519-010) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (97.2%) (Figure 7.5).

#### **7.3.2.6 FbNp-25 Summary**

The recovery of sufficient phytolith numbers ( $n \geq 250$ ) from all five samples at FbNp-25 allows for a strengthened level of confidence in the inferences made about the nature and timing of vegetation changes reflected at the Thundercloud site. The high phytolith yields from these samples provide evidence that high phytolith counts at FbNp-25 may be used to indicate extended periods of landscape stability and pedogenesis. This hypothesis is further supported through the geomorphic study carried out by Burt (1997) and the archaeological data recorded by Webster (1999). Both these lines of evidence provide support to suggest these samples are indicative of cumelic regosols.

Sample FbNp-25-2 suggests very warm, dry summer conditions at the site 5000 to  $4040 \pm 90$  BP which may suggest a post-Hypsithermal period of relative warmth within the Opimihaw Creek Valley. Samples FbNp-25-3 and FbNp-25-4 ( $4040 \pm 90$  BP,  $3315 \pm 50$  BP, and  $3150 \pm 50$  BP) suggest cool spring/fall conditions and warm, dry summers, though less warm and dry than indicated by sample FbNp-25-2. Samples FbNp-25-7 and FbNp-25-8 suggest cool, moderate conditions in the Late Holocene ( $< 2500$  BP). The samples from FbNp-25 are discussed further in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

#### **7.3.3 Wolf Willow (FbNp-26)**

The Wolf Willow site is located on a point bar along the Opimihaw Creek. The stratigraphic profile indicates a typical point bar sequence and records the eastward migration of the creek to its current location east of the site (Stumborg 2016). Pins marking the cultural levels from previous excavations were not recovered during sediment sampling at this site. However, these samples were recovered during active excavation and therefore cultural affiliations are

known. Figure 7.7 presents the relative frequency of short-cell morphotypes within each sample at FbNp-26. Figure 7.8 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths by depth at FbNp-26. Figure 7.9 represents the stratigraphic profile recorded during sediment sampling.

#### **7.3.3.1 FbNp-26-1**

This sample was taken from a depth of 72-76 cmbs. A radiocarbon date from cultural level 4 above provides a minimum date of  $4860 \pm 30$  BP for this sample (Stumborg 2016:57). No maximum date is currently available for this sample. A count of 250 phytoliths was reached for this sample.

Archaeological excavations described this stratum as ranging from light clay (Stumborg 2016:63,70), to clay/course sand (Stumborg 2016:67), to gravelly sand (Stumborg 2016:191). Pebbles and gravels were not noted in the sediment sample during the manual disaggregation phase. During the process of sieving out the  $>250 \mu\text{m}$  fraction, only a small amount was recorded as caught in the sieve. These observations suggest the sample was comprised of mainly fine-grained sands and smaller particles which suggests this sample is not associated with the lower gravel lens present at the site. A high phytolith yield ( $n \geq 250$ ) may suggest this sample relates to an extended period of stability.

The phytolith morphological data for this sample suggests a dominance of Pooideae morphotypes (82.0%), suggesting overall cool, temperate conditions. Within Pooideae, a dominance of the keeled (40.4%) morphotype indicates drought-tolerant taxa. Increased Chloridoideae (18.0%) suggests warm temperatures and dry moisture conditions (Figure 7.7; Figure 7.8). Overall, the data suggest cool, spring/fall conditions with warm, dry summers.

#### **7.3.3.2 FbNp-26-2**

This sample was taken from a depth of 64-66 cmbs and falls between the depths recorded for cultural levels 4 and 5 (Mampe 2015:106). Radiocarbon dates from strata above and below this sample depth confine the age of this sample to  $4860 \pm 30$  BP to  $4540 \pm 30$  BP (Stumborg 2016:57). A count of 250 phytoliths was reached for this sample.

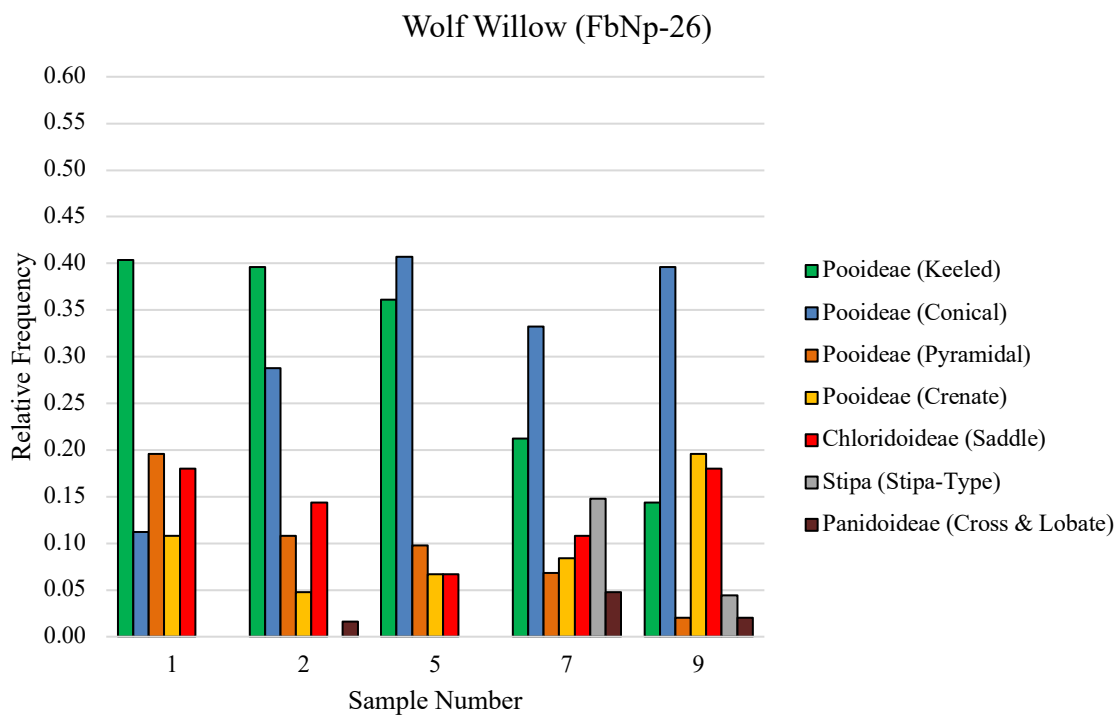


Figure 7.7. Relative frequency of short-cell phytoliths by taxa for FbNp-26.

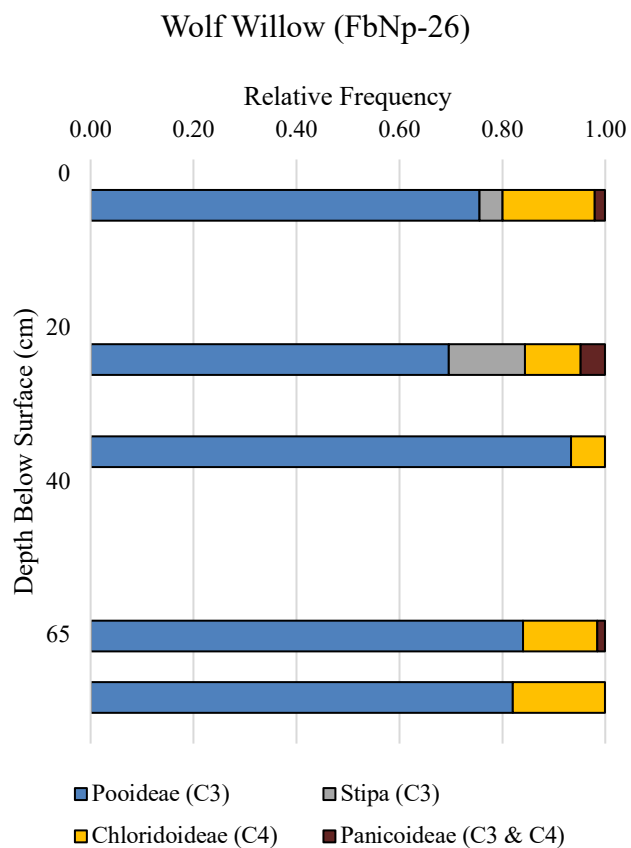


Figure 7.8: Relative frequency of short-cell phytoliths in samples from FbNp-26.

### Profile of Wolf Willow (FbNp-26)

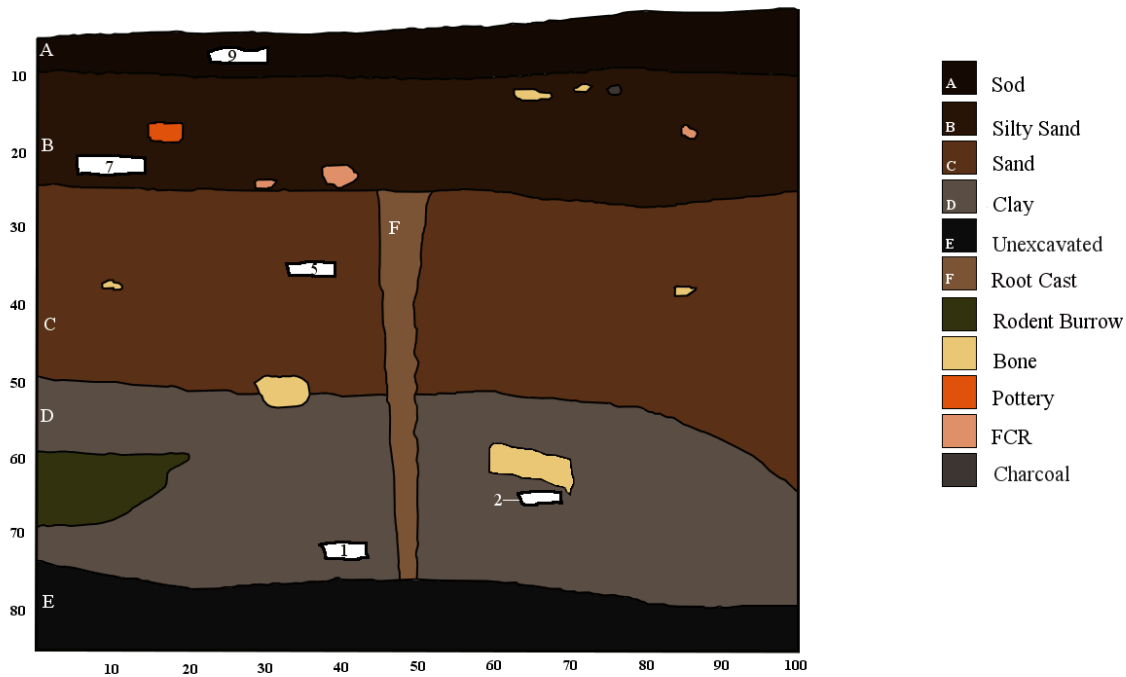


Figure 7.9: Wall profile of Wolf Willow (FbNp-26) showing phytolith sample locations. Axes are measured in centimetres.

Archaeological excavations describe this stratum as ranging from light clay (Stumborg 2016:63,70), to clay/course sand (Stumborg 2016:67), to gravelly sand (Stumborg 2016:191). Pebbles and gravels were not noted in the sediment sample during the manual disaggregation phase. During the process of sieving out the  $>250 \mu\text{m}$  fraction, only a small amount was recorded as caught in the sieve. These observations suggest the sample was comprised of mainly fine-grained sands and smaller particles which suggests this sample is not associated with the lower gravel lens at the site. A high phytolith yield ( $n \geq 250$ ) may suggest this sample relates to an extended period of stability.

The phytolith morphological data for this sample suggests a dominance of Pooideae (84.0%) morphotypes, suggesting cool, damp conditions. Within the Pooideae, a high proportion of the keeled (39.6%) morphotype suggests drought tolerant taxa. A high frequency of the Chloridoideae (14.4%) morphotype suggests warm, dry summer conditions. The presence of Panicoideae (1.6%) morphotypes suggests warm, humid conditions (Figure 7.7; Figure 7.8). The overall phytolith assemblage suggests cool, damp spring/fall and warm summer temperatures.



#### 7.3.3.3 FbNp-26-5

This sample was taken from a depth of 34-36 cmbs and falls within the depth range recorded for cultural level 3 (Mampe 2015:86). Cultural level 3 is associated with McKean series projectile points (Mampe 2015:90-92; Stumborg 2016:125) and a radiocarbon date of  $3640 \pm 30$  BP (Stumborg 2016:57). Phytolith counts for this level were moderate ( $n=194$ ).

The depth of this sample is associated with a thin paleosol overlain by coarse sandy gravels. Pebbles were noted in the sediment sample during the manual disaggregation phase which may suggest incorporation of the overlying gravel layer within this sample. Incorporation of the gravel layer within the sample may explain the moderate phytolith yield. Or, the moderate phytolith yield ( $n=194$ ) from this sample may be an indication of association with the thin paleosol. Given the data from other sites within WHP, it is likely this is the case.

The phytolith morphological data for this sample suggests a dominance of Pooideae (93.3%), suggesting cool, moderate conditions. Within the Pooideae, a high proportion of the conical (40.7%) morphotype suggests cool, temperate conditions, while the keeled (36.1%) morphotype suggests drought-tolerant taxa. A decrease in Chloridoideae (6.7%) over sample FbNp-26-2 above suggests lower temperatures and increased moisture but does not suggest cool, wet conditions at this time (Figure 7.7; Figure 7.8). Overall, this sample suggests conditions were likely cool to warm and dry.

#### 7.3.3.4 FbNp-26-7

This sample was taken from a depth of 21-23 cmbs and falls within the depth range recorded for cultural level 2 (Mampe 2015:59). Cultural level 2 is associated with Prairie Side-notched projectile points, suggesting an age of 1100-600 BP. Archaeological investigations associate cultural level 2 with a thick, dark brown humic paleosol (Mampe 2015:59). These observations, in association with a high phytolith count ( $n \geq 250$ ), suggest this sample represents an extended period of landscape stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (69.6%), suggesting cool, temperate conditions. Within the Pooideae, the keeled (21.2%) morphotype suggests drought-tolerant taxa. A relatively high proportion of *Stipa* (14.8%) suggests cool, wet conditions, however, this genus also exhibits a high drought tolerance. A decrease in Chloridoideae (10.8%) over sample FbNp-26-9 below suggests decreased temperatures and increased moisture. The presence of Panicoideae (4.8%) suggests warm, humid

conditions (Figure 7.7; Figure 7.8). Overall, the data suggest cool, dry spring/fall conditions with warm summers.

A  $\delta^{13}\text{C}$  measurement of -27.8‰ (Beta 485183) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (84.4%) (Figure 7.8).

#### **7.3.3.5 FbNp-26-9**

This sample was taken from a depth of 2-5 cmbs and falls within the depth range recorded for cultural level 1 (Mampe 2015:44). Cultural level 1 is associated with Plains Side-notched projectile points, Mortlach pottery (Stumborg 2016:101), and a radiocarbon date of  $150\pm 30$  BP (Stumborg 2016:57). Archaeological excavations indicate cultural level 1 is located in “a dark brown humic soil which represents the modern A-horizon” (Mampe 2015:44). This, in association with a high phytolith count ( $n\geq 250$ ) suggest this sample represents a period of stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (75.6%), suggesting cool, temperate conditions. Within the Pooideae, the keeled (14.4%) morphotype coupled with elevated proportions of crenate (19.6%) morphotypes suggests dry soils and drought-tolerant taxa, while the dominance of conicals (39.6%) suggests cool, temperate conditions. A high proportion of Chloridoideae (18.0%) suggests hot and dry conditions. The presence of *Stipa* (4.4%) suggests cool, wet conditions, however, this genus also exhibits a high drought tolerance. The presence of Panicoideae (2.0%) suggests warm, humid conditions (Figure 7.7; Figure 7.8). Overall, the data reflect cool, dry spring/fall conditions with warm, dry summers.

#### **7.3.3.6 FbNp-26 Summary**

Paleosols reflecting periods of stability allowing for vegetation growth and pedogenesis are recorded throughout the site profile. The recovery of high phytolith counts from samples FbNp-26-1, FbNp-26-2, FbNp-26-7, and FbNp-26-9 suggest these samples are associated with developed paleosols. The recovery of moderate phytolith counts from sample FbNp-26-5 likely indicates association with a weak paleosol.

Sample FbNp-26-1 suggests sometime before  $4860\pm 30$  BP conditions at the site were likely cool in spring/fall with warm, dry summers. Unfortunately, there is no maximum date

available for this sample, which limits its interpretive value. Cool, damp spring/fall conditions and warm summer temperatures are suggested from  $4860 \pm 30$  BP to  $4540 \pm 30$  BP by sample FbNp-26-2. Sample FbNp-26-5 suggests cool-warm temperatures and dry conditions at  $3640 \pm 30$  BP. Samples FbNp-26-9 and FbNp-26-7 suggest cool, dry spring/fall conditions with warm summers after  $2530 \pm 30$  BP. All five samples from FbNp-26 are discussed in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

#### **7.3.4 Amisk (FbNp-17)**

The Amisk site is located on a colluvial slope where slopewash and mass wasting events are the main geomorphic processes. Organic-rich stratigraphic layers suggest episodes of stability and pedogenesis throughout the site profile (Burt 1997:154). Pins marking the cultural levels from previous excavations were not recovered during sediment sampling. Figure 7.10 presents the relative frequency of short-cell morphotypes within each sample at FbNp-17. Figure 7.11 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths by depth at FbNp-17. Figure 7.12 represents the stratigraphic profile recorded during sediment sampling.

##### **7.3.4.1 FbNp-17-2**

This sample was taken from a depth of 85-90 cmbs. A radiocarbon date from cultural level 4 below provides a minimum date of  $4015 \pm 195$  BP for this sample. Burt (1997:151-153) identified sediments related to cultural level 4 as belonging to a cumulic regosol. Archaeological investigations also associate the cultural materials from level 4 with a paleosol (Amundson 1986:57). The data presented here, in association with a high phytolith count ( $n \geq 250$ ) suggest this sample represents an extended period of stability and pedogenesis.

The phytolith morphological data for this sample suggests a dominance of Pooideae (69.2%) morphotypes, suggesting cool, temperate conditions. Within the Pooideae, a high frequency of crenate (35.6%) phytoliths suggests cool, dry soils. The presence of Chloridoideae (8.8%) suggests warm, dry summers. A high frequency of Panicoideae (12.8%) suggests warm, humid conditions (Figure 7.10; Figure 7.11). Overall, these results reflect a relatively dry environment with cool spring/fall and warm summer conditions.

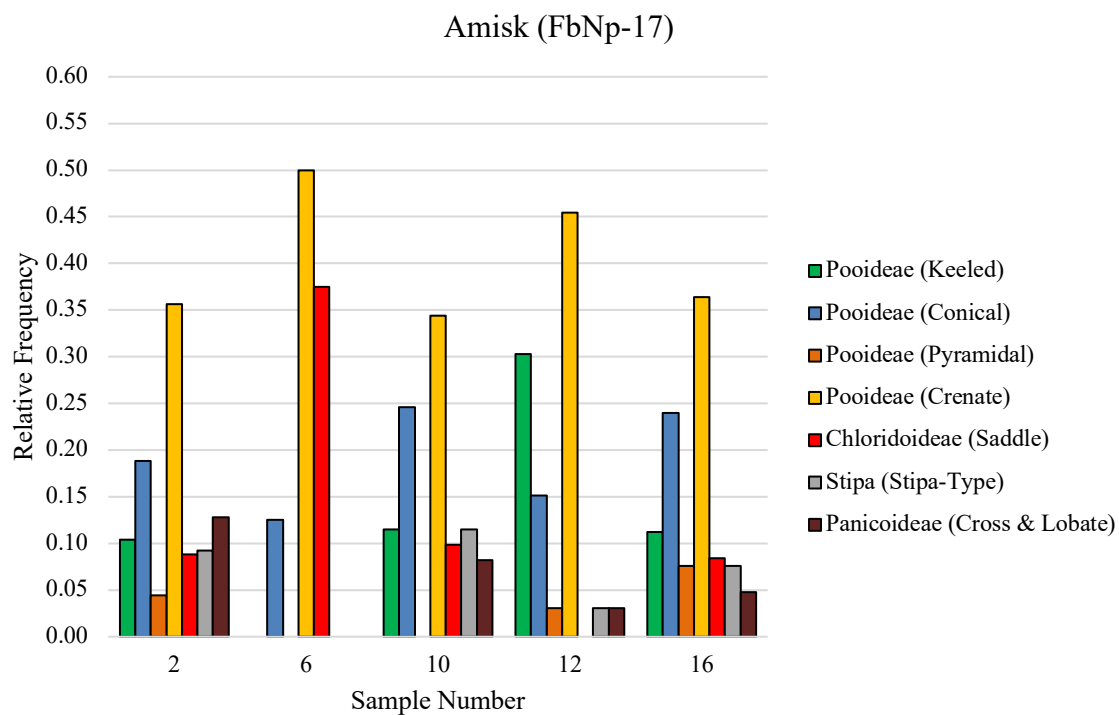


Figure 7.10: Relative frequency of short-cell phytoliths in samples from FbNp-17.

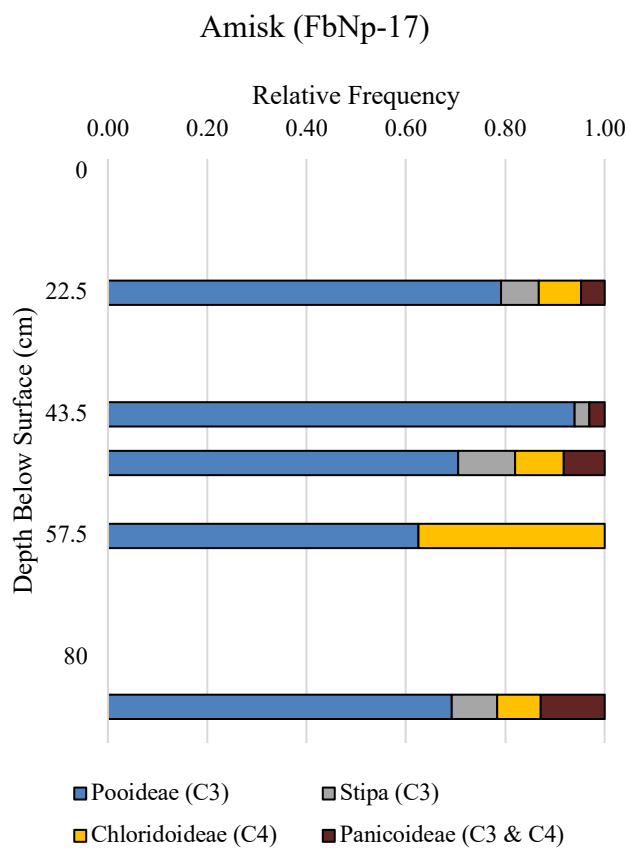


Figure 7.11: Relative frequency of short-cell phytoliths by taxa for FbNp-17.

### Profile of Amisk (FbNp-17)

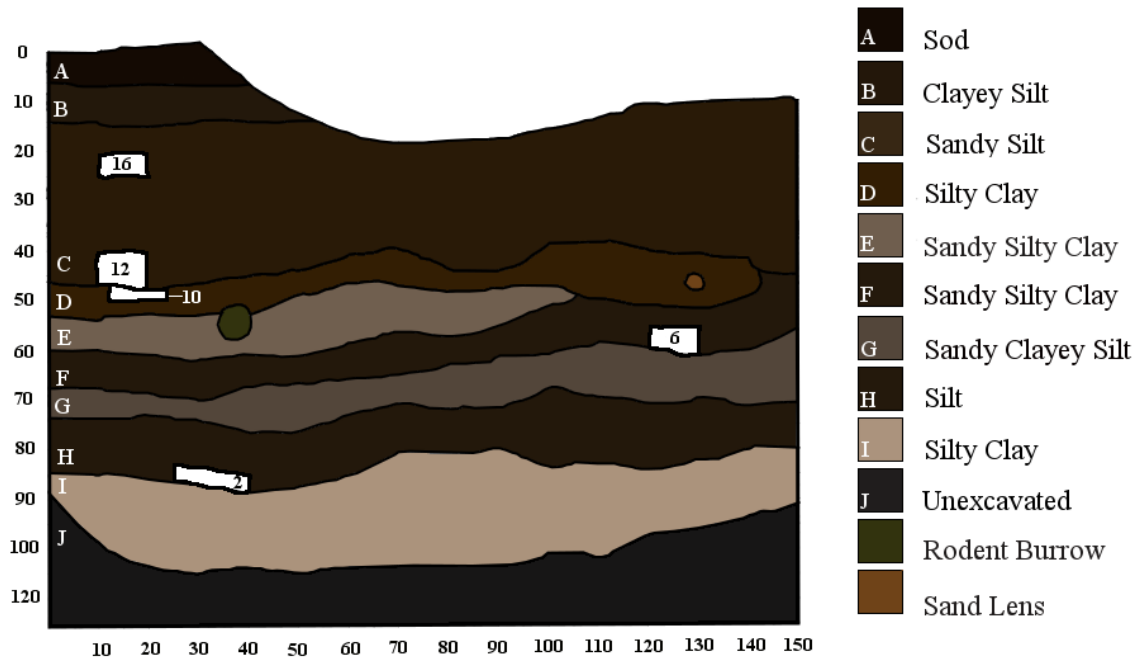


Figure 7.12: Wall profile of Amisk (FbNp-17) showing phytolith sample locations. Axes are measured in centimetres.

Two  $\delta^{13}\text{C}$  measurements were obtained for this sample -30.4‰ (B1718-519-002) and -31.5‰ (Beta 485184). These values fall within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. These values support the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (78.4%) (Figure 7.11). The relatively low  $\delta^{13}\text{C}$  value in combination of the relatively high number of phytoliths indicative of Panicoideae grasses may suggest a high frequency of  $\text{C}_3$  species within the Panicoideae subfamily. Both  $\text{C}_3$  and  $\text{C}_4$  species belong to this family in approximately a 50:50 ratio (Twiss 1992).

#### 7.3.4.2 FbNp-17-6

This sample was taken from a depth of 55-60 cmbs and falls within the depth ranges recorded for cultural levels 3 and 4 (Walker et al. 1986:38-40). Radiocarbon dates from cultural levels 4 ( $4015 \pm 195$  BP) and 3 ( $3530 \pm 110$  BP) provide limiting dates for this sample (Walker et al. 1986:38-40). Phytolith counts for this sample are quite low ( $n=48$ ). The depth of this sample is associated with slightly gravelly sand and low organic matter (Burt 1997:153). Coarse sand and small pebbles were noted in the sample during the manual disaggregation phase. Burt (1997:153) noted a rapid sedimentation rate for this strata which may have resulted in reduced vegetal growth. It is likely the low phytolith count in this sample is an indication of landscape

instability at this time. Due to low phytoliths yields this sample was omitted from paleoenvironmental interpretation.

#### **7.3.4.3 FbNp-17-10**

This sample was taken from a depth of 48-50 cmbs and falls within the depth range recorded for cultural level 3 (Walker et al. 1986:40). Cultural level 3 is associated with a radiocarbon date of  $3530 \pm 110$  BP (Walker et al. 1986:40). Phytolith counts for this level were below the 250 count target, but still moderately high ( $n=183$ ). The depth of this sample is associated with a paleosol, as well as a period of erosion (Burt 1997:153). Archaeological excavations associate cultural level 3 with a thin paleosol (Amundson 1986:54). It is likely the moderate phytolith count of this sample may be an indication of a weakly developed paleosol or a shorter period of stability at this time.

The phytolith morphological data for this sample suggests a dominance of Pooideae (70.5%) morphotypes, suggesting cool, temperate conditions. Within the Pooideae, relatively high crenate (34.4%) morphotypes suggests cool temperatures and dry soils. *Stipa* (11.5%) reflects cool, wet conditions however this taxon also exhibits a high drought tolerance. Chloridoideae (9.4%) morphotypes suggest warm, dry summer months. The presence of Panicoideae (8.2%) suggests warm, wet conditions (Figure 7.10; Figure 7.11). Overall, the data suggests cool, dry spring/fall with warm, wet summer. It is important to note, however, that phytolith yields were moderate for this sample and therefore interpretations are tentative.

#### **7.3.4.4 FbNp-17-12**

This sample was taken from a depth of 40-47 cmbs, which correlates with depths recorded for cultural level 3 (Walker et al. 1986:40). Cultural level 3 is associated with a radiocarbon date of  $3530 \pm 110$  BP (Walker et al. 1986:40). Phytolith counts for this level were low ( $n=99$ ). The depth of this sample is associated with a paleosol, as well as a period of erosion (Burt 1997:153). Archaeological excavations also associate cultural level 3 with a thin paleosol (Amundson 1986:54). It is likely the low phytolith count of this sample may be an indication of a weakly developed paleosol or a shorter period of stability at this time.

The phytolith morphological data for this sample indicates a dominance of Pooideae (93.9%) morphotypes, suggesting cool, damp conditions. Within the Pooideae, crenate (45.45%) and keeled (30.3%) morphotypes suggest cool temperatures and dry soils, but they also represent taxa that are cold, heat, and drought tolerant. The absence of Chloridoideae indicates cool

temperatures. The limited presence of Panicoideae (3.3%) may suggest moderately warm, wet summer months (Figure 7.10; Figure 7.11). Overall, conditions were likely cool and dry with warm, humid summers. The relatively low count for this sample, however, does make this interpretation more tentative.

#### 7.3.4.5 FbNp-17-16

This sample was taken from a depth of 20-25 cmbs, which correlates with cultural level 1 (Walker et al. 1986:36). Cultural level 1 has radiocarbon dates of  $905 \pm 155$  BP and  $635 \pm 85$  BP (Walker et al. 1986:40). A count of 250 phytoliths was reached for this sample. Burt (1997:154) identified sediments related to cultural level 1 as high in organic content. Archaeological investigations associate this level with a thick, sandy loam (Amundson 1986:59). The data presented here suggest this stratum likely relates to an extended period landscape stability and pedogenesis.

A dominance of Pooideae (79.2%) morphotypes evidences cool, temperate conditions. Within the Pooideae, a dominance of crenate (36.4%) morphotypes suggests cool temperatures and dry soils. *Stipa* (7.6%) reflects cool, wet conditions, though this genus can thrive in a hot summer if there is adequate moisture. The presence of Chloridoideae (8.4%) suggests warm, dry conditions. Panicoideae (4.8%) morphotypes suggest warm, humid conditions (Figure 7.10; Figure 7.11). Overall, the data suggests cool, dry spring/fall with increased summer temperatures compared with modern conditions.

Two  $\delta^{13}\text{C}$  measurements were obtained for this sample, -27.8‰ (B1718-519-003) and -28.6‰ (Beta 485185). These values fall within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. These values support the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (86.8%) (Figure 7.11).

The associated radiocarbon date of this sample suggests a Medieval Warm Period age (1000-700 BP). The increased summer temperatures interpreted from this sample may be related to increased temperatures during the Medieval Warm Period. These results fit with climate data collected from elsewhere in Saskatchewan (Section 4.3.3), however, phytolith data from sites elsewhere in the valley suggest that this period may be more variable than previously thought (Section 7.4).

#### 7.3.4.6 FbNp-17 Summary

Given the location and low elevation of the Amisk site within the Valley Slope Zone (Section 2.5.3.2), it seems likely that large flood events could have reached the site in the past, however, the sedimentary sequence does not indicate any flood events at the site (Burt 1997:154). Sample FbNp-17-6 produced a very low phytolith count ( $n=48$ ). This is likely due to the possible association of this sample with a period of landscape instability. The moderate phytolith counts from samples FbNp-17-10 and FbNp-17-12 may potentially indicate associations with weakly developed paleosols. High phytolith counts ( $n \geq 250$ ) from samples FbNp-17-2 and FbNp-17-16 may indicate these samples are associated with well-developed paleosols. These samples suggest that phytolith counts at FbNp-17 may be used as an indicator of past landscape (in)stability.

Sample FbNp-17-2 suggests dry conditions with a cool/spring fall and warm summer sometime prior to  $4015 \pm 195$  BP. Cool, dry spring/fall conditions with warm, moist summers at  $3530 \pm 110$  BP are suggested by samples FbNp-17-10 and FbNp-17-12. Sample FbNp-17-16 suggests cool, dry spring/fall conditions with warm summer temperatures from  $905 \pm 155$  BP to  $635 \pm 85$  BP, which correlates well with the Medieval Warm Period. Due to very low phytolith yields, sample FbNp-17-6 was excluded from paleoenvironmental interpretation. Samples FbNp-17-2, FbNp-17-10, FbNp-17-12, and FbNp-17-16 are discussed in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

#### 7.3.5 Cut Arm (FbNp-22)

The Cut Arm site is located within a drainage swale on the southwestern uplands of the Opimihaw Creek Valley. Overland and debris flows are the main geomorphic processes evidenced at the site. Pins marking the cultural levels from previous excavations were not recovered during sediment sampling. Figure 7.13 presents the relative frequency of short-cell morphotypes within samples at FbNp-22. Figure 7.14 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths by depth at FbNp-22. Figure 7.15 represents the stratigraphic profile recorded during sediment sampling.



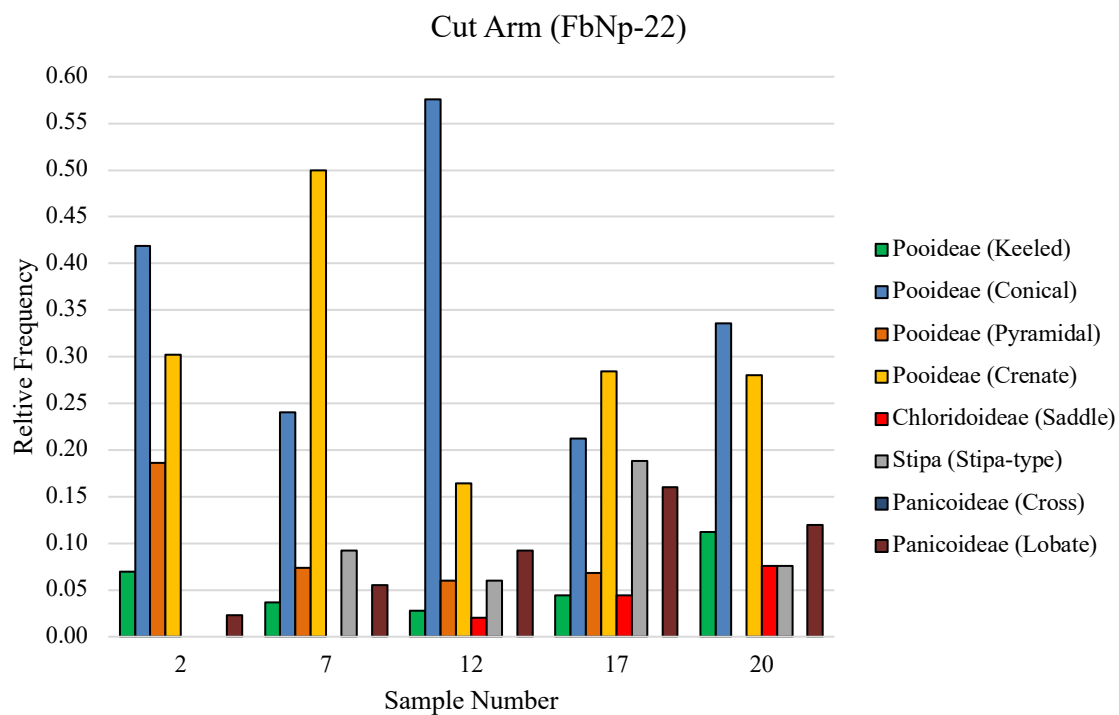


Figure 7.13: Relative frequency of short-cell phytoliths in samples from FbNp-22.

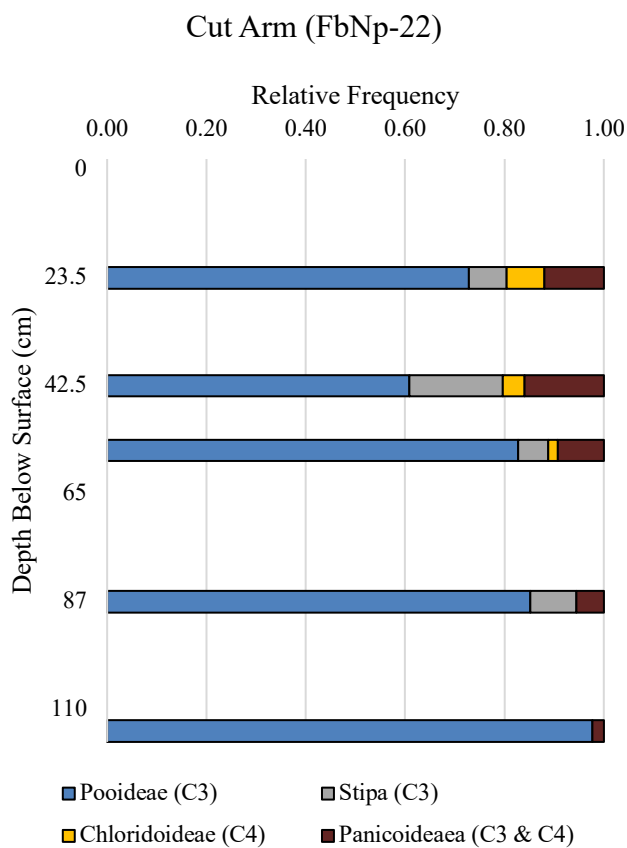


Figure 7.14: Relative frequency of short-cell phytoliths by taxa for FbNp-22.

### Profile of Cut Arm (FbNp-22)

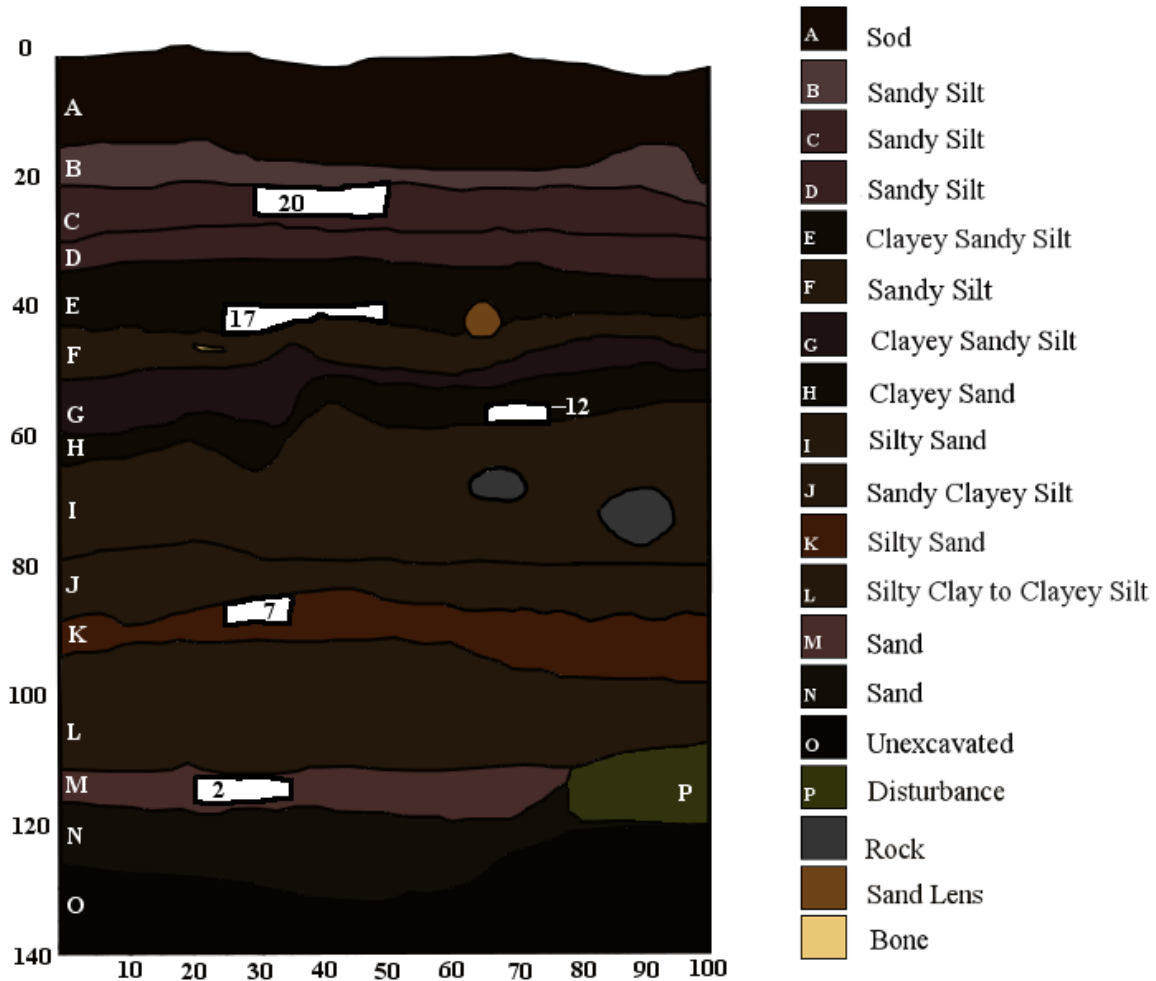


Figure 7.15: Wall profile of Cut Arm (FbNp-22) showing phytolith sample locations. Axes are measured in centimetres.

#### 7.3.5.1 FbNp-22-2

This sample was taken from a depth of 113-117 cmbs. Radiocarbon dates from cultural levels 6 and 9 provide a maximum and minimum age for this sample of  $3802 \pm 55$  BP and  $3178 \pm 50$  BP, respectively (Smith 2012:36). Phytolith counts for this level were moderate ( $n=129$ ). The depth of this sample is associated with periodic debris flow events punctuated by periods of stability and soil formation (Rutherford 2004:43-50). Given the moderate phytolith yield, this sample may be associated with a short period of landscape stability which may have resulted in reduced vegetation growth rates. The moderate phytolith count of this sample may be an indication of a brief period of stability and pedogenesis.

The phytolith data from this sample indicate a dominance of Pooideae (97.7%) morphotypes suggesting cool, temperate conditions. The presence of Panicoideae (2.3%) suggests warm, moist conditions (Figure 7.13; Figure 7.14). Overall, conditions were likely cool and temperate. It is important to note that low phytolith yields make this interpretation more tentative.

#### **7.3.5.2 FbNp-22-7**

This sample was taken from a depth of 85-89 cmbs, which falls within the depth range recorded for cultural level 6 (Smith 2012:119). Cultural level 5a above provides a minimum age of 2500-1400 BP based on Besant projectile points and a radiocarbon date from cultural level 8 below provides a maximum age of  $3387 \pm 50$  BP (Smith 2012:36). Phytolith counts for this sample are moderate (n=162).

The depth of this sample is associated with periodic debris flow events punctuated by periods of stability and soil formation. The moderate phytolith count of this sample may be indicative of a short period of landscape stability and pedogenesis. Given the association of the sample with an intact cultural level and a moderate phytolith count (n=162) it is likely this sample relates to a short period of landscape stability and pedogenesis.

The phytolith data indicate a dominance of Pooideae (85.2%) morphotypes which suggests cool, temperate conditions. Within the Pooideae, a high frequency of crenates (50.0%) suggests cool temperatures and dry soils. *Stipa* (9.26%) prefer cool, wet conditions but can dominate in a hot summer if adequate moisture is present. The presence of Panicoideae (5.6%) suggests warm, moist conditions (Figure 7.13; Figure 7.14). Overall, the assemblage reflects a cool, dry spring/fall with warm summer temperatures and moderate moisture conditions. It is important to note that low phytolith yields make this interpretation more tentative.

#### **7.3.5.3 FbNp-22-12**

This sample was taken from a depth of 55-58 cmbs, which falls within the depth ranges recorded for cultural levels 5a and 5b (Smith 2012:99-100). Besant projectile points (Smith 2012:99-100) from cultural level 5a suggests a minimum age of 2500-1400 BP, while a radiocarbon date from cultural level 6 below suggests a maximum age of  $3178 \pm 50$  BP (Smith 2012:36). The association of this stratum with a cultural level as well as a high phytolith count

( $n \geq 250$ ) suggests this sample relates to an extended period of landscape stability and pedogenesis.

The phytolith morphological data indicate dominance of Pooideae (82.8%) morphotypes, suggesting cool, damp conditions. The presence of *Stipa* (6.0%) suggests cool, wet conditions. The presence of Panicoideae (9.2%) suggests warm, humid conditions (Figure 7.13; Figure 7.14). Overall, conditions were likely cool in the spring/fall with warm, moist summers.

A  $\delta^{13}\text{C}$  measurement of -27.8‰ (B1718-519-004) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (88.8%) (Figure 7.14).

#### **7.3.5.4 FbNp-22-17**

This sample was taken from a depth of 40-45 cmbs and falls within the depth ranges recorded for cultural levels 4 and 5a (Smith 2012:81, 99). Avonlea pottery from cultural level 4 and Besant projectile points from cultural level 5a (Smith 2012:99-100) suggest an age range of 1050-2500 BP. The association of this stratum with a cultural level as well as a high phytolith count ( $n \geq 250$ ) suggests this sample relates to an extended period of landscape stability and pedogenesis.

A dominance of Pooideae (60.8%) morphotypes suggests cool, temperate conditions. Within the Pooideae, a high frequency of crenates (28.4%) suggests dry soils. A high proportion of *Stipa* (18.8%) suggests cool, wet conditions, though this genus can dominate in hot summer if there is adequate moisture. The presence of Chloridoideae (4.4%) suggests high summer temperatures. A high proportion of Panicoideae (16.0%) suggests warm, humid conditions (Figure 7.13; Figure 7.14). Overall, the data suggest warm temperatures and humid conditions.

A  $\delta^{13}\text{C}$  measurement of -25.8‰ (B1718-519-005) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data which suggests a dominance of  $\text{C}_3$  grasses (79.6%) (Figure 7.14). The higher  $\delta^{13}\text{C}$  value, when compared with other sites within the valley, may suggest a high frequency of  $\text{C}_4$  species within the Panicoideae subfamily. Both  $\text{C}_3$  and  $\text{C}_4$  species belong to this family in approximately a 50:50 ratio (Twiss 1992).

#### 7.3.5.5 FbNp-22-20

This sample was taken from a depth of 21-26 cmbs and falls within the depth ranges recorded for cultural levels 2 and 3 (Smith 2012:38, 51). A radiocarbon date from cultural level 2 provides a minimum date of 524±40 BP (Smith 2012:36) while Old Women's pottery from cultural level 3 provides a maximum date of 1400 BP. The association of this stratum with a cultural level as well as a high phytolith count ( $n \geq 250$ ) suggests this sample may relate to an extended period of landscape stability and pedogenesis.

A dominance of Pooideae (72.8%) suggests cool, temperate conditions. Within the Pooideae, a high frequency of the conical (33.6%) morphotype suggests cool, temperate conditions. A high frequency of Panicoideae (12.0%) indicates warm, humid conditions. The *Stipa* (7.6%) genus suggests cool, wet conditions though this genus can thrive in a hot summer if there is adequate moisture. The presence of Chloridoideae (7.6%) suggests hot, dry conditions (Figure 7.13; Figure 7.14). Overall, the assemblage reflects increased temperatures above modern conditions with moderate moisture levels.

A  $\delta^{13}\text{C}$  measurement of -28.8‰ (Beta 485186) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data which suggests a dominance of  $\text{C}_3$  grasses (80.4%) (Figure 7.14).

The Medieval Warm Period falls within the date range for this sample. The increased temperatures suggested by this sample may be a result of increased temperatures related to the Medieval Warm Period. Data from elsewhere in Saskatchewan suggests the Medieval Warm Period is associated with increased aridity rather than increased temperatures. Phytolith data from sites elsewhere in the Valley suggest that this period may be more variable than previously thought (See Section 7.4).

#### 7.3.5.6 FbNp-22 Summary

The location of the Cut Arm site on the upland of the creek valley differentiates it from the other sites within this study, which are located within in the valley slope and floodplain zones. The uppermost samples, FbNp-22-12, FbNp-22-17, and FbNp-22-20, are associated with intermittent paleosols separated by periodic overland flows. Moderate phytolith counts from FbNp-22-2 and FbNp-22-7 appear to be associated with short periods of landscape stability which may have resulted in reduced vegetation growth rates. The phytolith yields of these

samples suggests that phytolith counts can be used as an indicator of past landscape stability. Further, these samples suggest that high phytolith counts can be used to infer longer periods of landscape stability and pedogenesis, while moderate phytolith counts may indicate shorter periods of landscape stability at FbNp-22.

Sample FbNp-22-2 suggests cool, temperate conditions between  $3802 \pm 55$  BP to  $3178 \pm 50$  BP. Prior to  $3387 \pm 50$  BP, cool, dry spring and fall conditions are suggested by sample FbNp-22-7. Samples FbNp-22-17 ( $3387 \pm 50$  BP to ca. 1400 BP), FbNp-22-12 ( $3178 \pm 50$  BP to ca. 1400 BP) and FbNp-22-20 (ca. 1400 BP to  $524 \pm 40$  BP) suggest overall, warm, moist conditions. All five samples are discussed in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

### **7.3.6 Tipperary Creek (FbNp-1)**

The Tipperary Creek site is located on a point bar of the Opimihaw Creek. Repeating periods of floodplain deposition followed by periods of stability and soil formation are reflected in the site geomorphology. Pins marking the cultural levels from previous excavations were recovered during sediment sampling (Figure 7.18). This facilitated the correlation of samples FbNp-1-6 and FbNp-1-25 with known cultural occupations at the site. In the case of FbNp-1-31 the pins demonstrated a lack of correlation with any known cultural occupation. Figure 7.16 presents the relative frequency of short-cell morphotypes at FbNp-1. Figure 7.17 presents the relative frequency of Pooideae, Chloridoideae, Panicoideae, and *Stipa*-type phytoliths at FbNp-1. Figure 7.18 represents the stratigraphic profile recorded during sediment sampling.

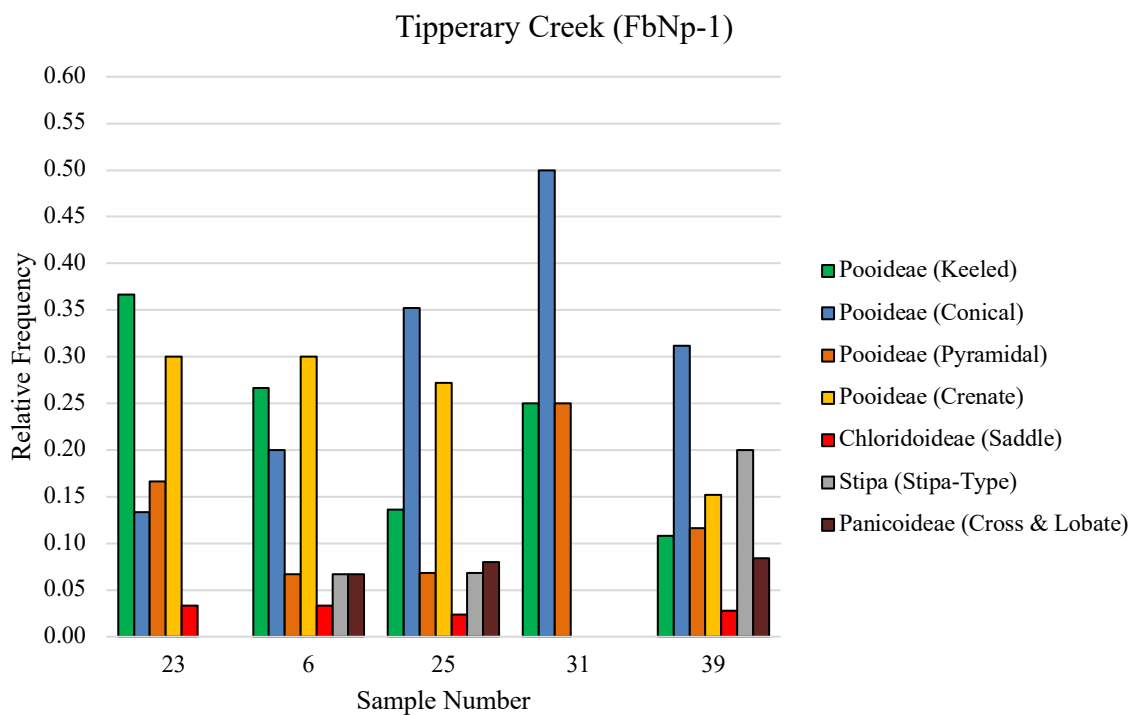


Figure 7.16: Relative frequency of short-cell phytoliths in samples from FbNp-1.

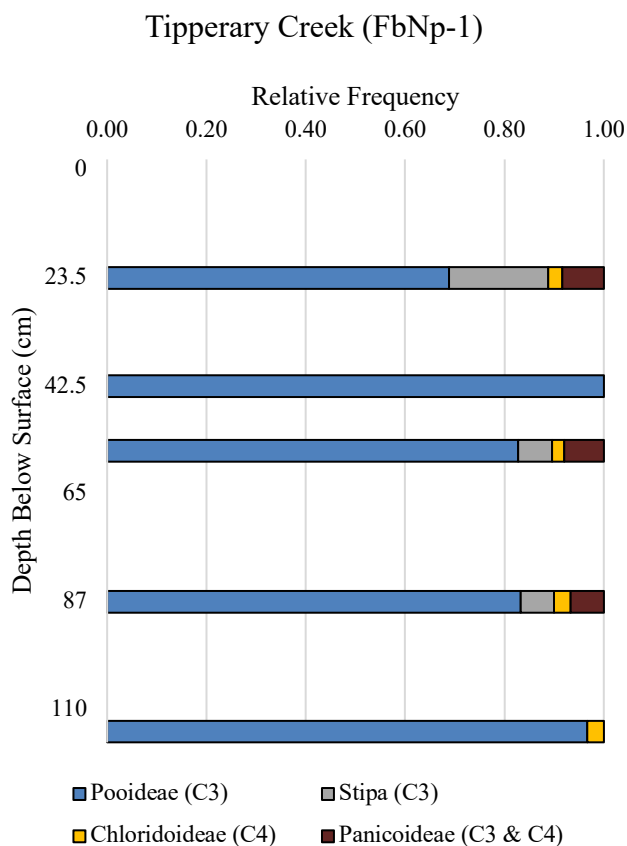


Figure 7.17: Relative frequency of short-cell phytoliths by taxa for FbNp-1.

# Profile of Tipperary Creek (FbNp-1)

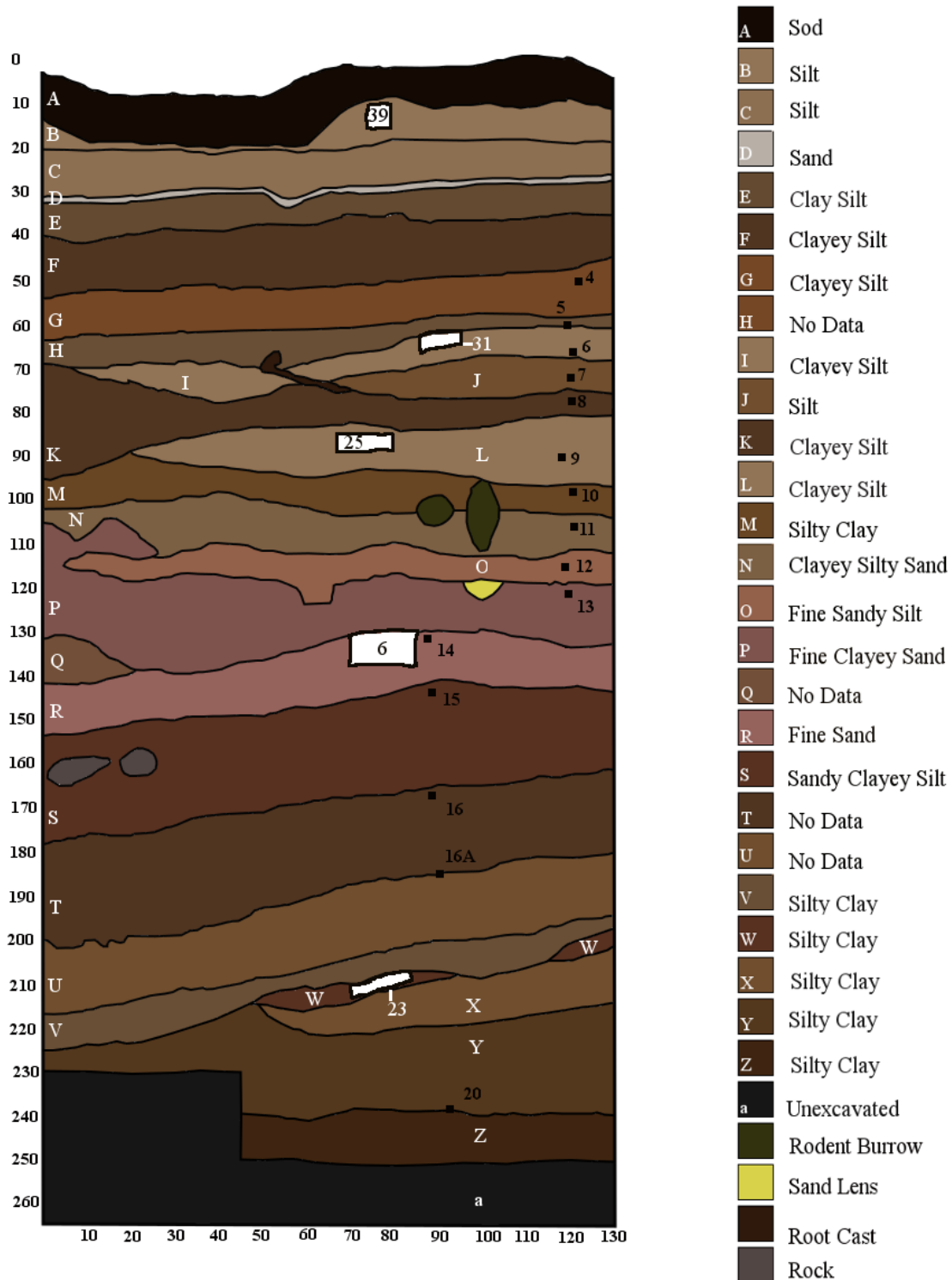


Figure 7.18: Wall profile of Tipperary Creek (FbNp-1) showing phytolith sample locations. Axes are measured in centimetres.



#### **7.3.6.1 FbNp-1-23**

This sample was taken from 190-192 cmbs. Current estimations bracket the age of this sample to 2800 BP to 1505±75 BP (Burt 1997:116). Phytolith counts for this sample were low (n=30). The depth of this sample is associated with mass movement or slopewash events associated with lateral movement of the stream (Burt 1997:116). This information, in association with low phytolith counts and a lack of association with a cultural occupation suggests this sample may be related to a period of landscape instability associated with mass movement or slopewash events. Due to the low phytolith yields this sample is omitted from paleoenvironmental interpretation.

#### **7.3.6.2 FbNp-1-6**

This sample was taken from 131-137 cmbs. Stratigraphic association with pin #14 from previous archaeological excavations suggests this sample is associated with cultural level 14 (Figure 7.18). Current estimations bracket the age of this stratum to 2800 BP to 1505±75 BP (Burt 1997:116). Phytolith counts for this sample were low (n=90). Stratigraphic and archaeological evidence suggest this stratum, including the cultural material, was redeposited by fluvial processes associated with floodplain deposition and proximity to the streambed (Burt 1997:94-95; Walker et al. 1987:39). This landscape instability may have resulted in reduced vegetation growth during this period. This may account for the low phytolith yield of this sample. The low phytolith count from this sample may also be indicative of a period of landscape instability and reduced rates of pedogenesis. Due to the low phytolith yields this sample was omitted from paleoenvironmental interpretation.

#### **7.3.6.3 FbNp-1-25**

This sample was taken from 85-90 cmbs and lies between depths recorded for cultural levels 9 and 10 (Walker et al. 1987:34, 37). Stratigraphic association with pin #9 from previous archaeological excavations (Figure 7.18) indicates this sample is associated with cultural level 9, which has been radiocarbon dated to 945±135 BP (Walker 1987:34). Association with an intact cultural level and a high phytolith yield (n≥250) implies the presence of a paleosol and a stable land surface at this time.

A dominance of Pooideae (82.8%) morphotypes suggests cool, damp conditions. Within the Pooideae, crenate forms (27.2%) suggest cool temperatures and dry soils. *Stipa* (6.8%) morphotypes reflect cool, wet conditions, however, this taxon also exhibits a high drought

tolerance. The presence of the Panicoideae (8.0%) morphotype suggests warm summer temperatures and increased moisture (Figure 7.16; Figure 7.17). At this time, conditions were likely warm and wet, but slightly dry during the middle of summer.

The associated date range for this sample correlates with the onset of the Medieval Warm Period (MWP). The increased temperatures suggested by this sample may be a result of increased temperatures related to the Medieval Warm Period. Data from elsewhere in Saskatchewan suggests the Medieval Warm Period is associated with increased aridity rather than increased temperatures. Phytolith data from sites elsewhere in the valley suggest that this period may be more variable than previously thought (See Section 7.4).

#### **7.3.6.4 FbNp-1-31**

This sample was taken from 63-65 cmbs and lies between depths recorded for cultural levels 5 and 6. This sample was located between pins #5 and #6 from previous archaeological excavations (Figure 7.18), suggesting this sample lies between cultural occupations 5 and 6 (Walker et al. 1987:29, 32). A maximum age of  $790 \pm 135$  BP is provided by cultural level 6 (Walker et al. 1987:32) and a minimum age of  $510 \pm 70$  BP is provided by cultural level 5 (Walker et al. 1987:29). Phytolith counts for this sample were very low ( $n=24$ ).

The depth of this sample suggests it was taken between paleosols and likely represents active floodplain deposition (Burt 1997:113) which would prevent vegetative growth. The low phytolith count and lack of association with a cultural occupation may be indicative of a period of landscape instability. Due to the low phytolith yields this sample was omitted from paleoenvironmental interpretation.

#### **7.3.6.5 FbNp-1-39**

This sample was taken from 10-15 cmbs. Radiocarbon dates of  $<100$  BP from cultural level 1 (Walker et al. 1987:25) above and  $380 \pm 70$  BP (Walker et al. 1987:27) from cultural level 2 below provide limiting dates. Burt (1997:114) identifies this as a thick, organic-rich stratum. A high phytolith yield ( $n \geq 250$ ) in association with Burt's data, suggests this stratum represents a period of landscape stability and pedogenesis.

A dominance of Pooideae (68.8%) morphotypes suggests cool, temperate conditions. A high proportion of *Stipa* (20%) morphotypes suggests cool, wet conditions; however, this taxon also exhibits a high drought tolerance. The presence of Panicoideae (8.4%) suggests warm, humid summer conditions. The presence of Chloridoideae (2.8%) suggests warm, dry conditions

(Figure 7.16; Figure 7.17). Overall, the data reflects cool, moist spring/fall and warm, moist summer conditions.

A  $\delta^{13}\text{C}$  measurement of -27.3‰ (B1718-519-001) was obtained from this sample. This falls within the expected range of  $\delta^{13}\text{C}$  values of phytoliths for  $\text{C}_3$  plants. This value supports the results of the phytolith morphological data, suggesting a dominance of  $\text{C}_3$  grasses (88.8%) (Figure 7.17).

#### **7.3.6.6 FbNp-1 Summary**

The uppermost 100 cm at the site are associated with thinly laminated paleosols that represent repetitive periods of floodplain deposition with intermittent periods of stability and pedogenesis. This fluvial history influenced the phytolith record of the upper 100 cm of the site. Low phytolith numbers associated with sample FbNp-1-23 are likely the result of mass movement or slopewash (Burt 1997:116) events which likely limited vegetation growth. Samples FbNp-1-39 and FbNp-1-25 yielded high phytolith counts ( $n \geq 250$ ) and are associated with paleosols. Samples FbNp-1-6 and FbNp-1-31 are likely associated with periods of floodplain deposition and landscape instability (Burt 1997:94-95) as suggested by low phytolith counts ( $n < 100$ ). These samples suggest that phytolith counts at FbNp-1 can be used as an indicator of past landscape (in)stability.

Due to low phytolith yields, samples FbNp-1-23, FbNp-1-6, and FbNp-1-31 were excluded from paleoenvironmental interpretation. Overall warm and wet conditions with some dryness throughout the summer are suggested by sample FbNp-1-25 at  $945 \pm 135$  BP, which corresponds with the Medieval Warm Period. Sample FbNp-1-39 suggests cool, moist spring/fall and warm/moist summer conditions after  $380 \pm 70$  BP. Samples FbNp-1-25 and FbNp-1-39 are discussed in Section 7.4 below in reference to the broader climatic trends visible within the Opimihaw Creek Valley.

#### **7.4 Alignment of Phytolith Morphological Data and $\delta^{13}\text{C}$ Values with Saskatchewan Data**

The short-cell phytolith morphological data and  $\delta^{13}\text{C}$  values indicate that  $\text{C}_3$  grasses and plants dominated the vegetation within the Opimihaw Creek Valley throughout the past 5000 years. This should not be taken to imply that climate conditions within the Opimihaw Creek Valley were static throughout the late Holocene. Changes in the relative frequencies of  $\text{C}_3$  and  $\text{C}_4$  grasses as evidenced by the phytolith short-cell morphological data align chronologically with

climatic changes visible elsewhere in Saskatchewan. This suggests that vegetation within the Opimihaw Creek Valley was not immune to late Holocene climate changes. Below is a discussion of how the short-cell phytolith record from the Opimihaw Creek Valley aligns with climatic events recorded elsewhere in Saskatchewan.

The oldest period represented by the samples analyzed in this thesis dates from 5000-4000 BP. This timespan post-dates the Hypsithermal as identified elsewhere on the Northern Plains (see Section 4.2.2). The short-cell phytolith samples that date to this period suggest fluctuating temperature and moisture conditions at this time. Sample FbNp-26-1 suggests cool spring/fall conditions with warm, dry summers sometime before  $4860 \pm 30$  BP. Sample FbNp-26-2 ( $4860 \pm 30$  BP to  $4540 \pm 30$  BP) suggests cool, damp spring/fall conditions with warm summer temperatures. Sample FbNp-24-7 ( $4597 \pm 50$  BP and  $4168 \pm 40$  BP) suggests overall cool conditions with dry to temperate moisture conditions. Sample FbNp-17-2 suggests dry conditions with a cool spring/fall and warm summer sometime prior to  $4015 \pm 195$  BP. Sample FbNp-25-2 suggests very warm, dry summer conditions at some time between 5000 BP to  $4040 \pm 90$  BP.

Samples FbNp-26-1, FbNp-26-2, FbNp-24-7 suggest that conditions were likely ameliorating following peak Hypsithermal aridity within the Opimihaw Creek Valley by  $4860 \pm 30$  BP, though Sample FbNp-25-2 suggests that at some point between 5000 BP to  $4040 \pm 90$  BP conditions were very warm and dry. Taken together, the above samples suggest that the decline of the Hypsithermal was not linear, that the climate trended towards cooler and moister conditions overall but was punctuated by periods of warmth and aridity. These data fit with climate data collected from elsewhere in Saskatchewan. Peak Hypsithermal warmth and aridity appears to have occurred between 8000-6000 BP within Saskatchewan as indicated by various lines of evidence from locales south of WHP such as Oro Lake, Clearwater Lake, Chappice Lake, Harris Lake, and the Andrews site (Section 4.2.2). One exception is Ceylon Lake, where peak warming is argued to have occurred between 6000-5000 BP (Last 1990). Burt (1997:172) suggested that peak Hypsithermal warming within the Opimihaw Creek Valley had passed some time prior to 4600 BP, by which time moister climate conditions are reflected in the geomorphic record of the valley. The phytolith data supports this suggestion, indicating that cooler, moister conditions were present within the valley by  $4860 \pm 30$  BP. Overall, the phytolith data during this period correlate well with climate data from elsewhere in Saskatchewan.

Phytolith samples dating to the period from 4000-1000 BP represent a continuation of the trend toward cooler and more moist conditions within the Opimihaw Creek Valley. Samples FbNp-25-3 and FbNp-25-4 ( $4040 \pm 90$  BP to  $3150 \pm 50$  BP) and FbNp-26-5 ( $3640 \pm 30$  BP) suggest cool-warm spring/fall conditions with warm, dry summers. Overall cool and temperate conditions are suggested by FbNp-22-2 ( $3802 \pm 55$  BP to  $3178 \pm 50$  BP). Cool, dry spring/fall conditions with increased summer heat and moisture at  $3530 \pm 110$  BP are suggested by samples FbNp-17-10 and FbNp-17-12. Samples FbNp-22-7 ( $3387 \pm 50$  to ca. 1400 BP) suggests cool spring/fall conditions with warm, moist summers. FbNp-22-12 ( $3178 \pm 50$  BP to ca. 1400 BP) suggests overall warm temperatures and humid conditions. Cool conditions throughout the growing season are suggested by FbNp-25-7 (2500-1050 BP). Samples FbNp-22-17 (2500-1050 BP) suggests overall warm temperatures and humid conditions. Taken together, these samples suggest overall cooler and moister conditions, when compared with the previous period, are established at this time. The phytolith data suggest warm summers with cooler, moister spring/fall conditions from 4000-2500 BP, while the period from 2500-1000 BP may represent a period of fluctuating temperature and moisture conditions.

Climate data from elsewhere in Saskatchewan reflects fluctuating climate conditions 4000-1000 BP throughout the region. At Oro Lake conditions 5000-3200 BP were dry but punctuated with periods of prolonged moisture. Lacustrine conditions remained saline from 3200-1900 BP with an inferred increase in precipitation occurring at 1900 BP (Laird et al. 2007). Increased water levels at Chappice Lake are reflected from 2600-1000 BP. At Waldsea Lake, fluctuating moist-dry conditions were present, including a complete drying event of the lake sometime between 4000-3000 BP (Last & Schweyen 1985). Dry, warm conditions persisted from 2800-2000 BP, with the onset of cooler, moister conditions by 2000 BP (Last & Schweyen 1985). At Kenosee Lake, rapid infilling occurred from 3000-2000 BP with fluctuating water and salinity levels from 2300-2000 BP (Vance et al. 1997).

The data from Saskatchewan, coupled with phytolith samples that date to the Besant period (FbNp-22-7, FbNp-22-12, and FbNp-22-17) suggest evidence of a warm, moist period associated with the Besant period, a period in which coordinated bison hunting peaked on the Northern Plains. It is possible climate conditions favouring production of grasslands may have played a part in this hunting fluorescence.

The phytolith data dating to 4000-2500 BP suggest increased moisture within the Opimihaw Creek Valley, while climate data from elsewhere in Saskatchewan suggests a more fluctuating but also increased moisture regime. The data here suggest that moisture conditions within the Opimihaw Creek Valley may have been more stable 4000-2500 BP than elsewhere in Saskatchewan. By contrast, the phytolith data from 2500-1000 BP agree with data from elsewhere in Saskatchewan, which suggest fluctuating temperature and moisture conditions.

The final period represented by the samples analyzed in this thesis dates to <1000 BP. Samples FbNp-22-20 (ca. 1400 to  $524 \pm 40$  BP), FbNp-26-7 (ca. 1100-600 BP), FbNp-1-25 ( $945 \pm 135$  BP), and FbNp-17-16 ( $905 \pm 155$  BP and  $635 \pm 85$  BP), all likely relate to the Medieval Warm Period (1000-700 BP). Sample FbNp-17-16 and FbNp-26-7 suggest cool, dry spring/fall conditions with warm summer temperatures while overall warm and wet conditions are suggested by samples FbNp-22-20 and FbNp-1-25. Samples FbNp-26-9 and FbNp-1-39 indicate climate conditions within the Opimihaw Creek Valley were similar to modern conditions by  $380 \pm 70$  BP. Sample FbNp-26-9 suggests conditions were likely dry throughout the year, while sample FbNp-1-39 suggests moist conditions. The difference in the suggested moisture regime of these two samples is likely related to differences in fluvial processes at each site. Moist conditions at FbNp-1 are likely a result of proximity to both the Opimihaw Creek and the South Saskatchewan River and frequent overbank flooding.

Records from elsewhere in Saskatchewan that date to the Medieval Warm Period are associated with increased aridity, rather than increased temperatures. Records from Chappice Lake indicate perennial droughts from 1000-600 BP (Lemmen and Vance 1998; Vance et al. 1992). The record from Waldsea Lake suggests a period of increased dryness around 700 BP (Last & Schweyen 1985), and Kenosee Lake records indicate an increase in salinity and decrease in the lake level over modern levels at 600 BP (Vance et al. 1997). These results are typical of the time period, which is described as a period of increased aridity on the Northern Plains (Vance et al. 1991). Pollen records from Wolf Willow (FbNp-26) that date to the MWP also indicate a period of increased moisture within the Opimihaw Creek Valley ca. 1100-600 BP (Stuart & Walker 2017). This fits with the short-cell phytolith morphological data which suggests the Opimihaw Creek Valley likely experienced warmer temperatures coupled with an increased moisture regime. This is atypical of this period as recorded elsewhere in Saskatchewan, which typically sees an increase in arid and/or drought-like conditions during this time period (Vance et

al. 1991). The data from WHP fits with the hypotheses of Laird et al. (2007) and Fritz et al. (2000), who suggest the Medieval Warm Period cannot be characterized as just an increase in aridity. The phytolith data from WHP support this hypothesis with samples suggesting cool, dry spring/fall conditions with warm summer temperatures and other samples suggesting overall warm and wet conditions during this time period. Citing Laird et al. (2003), Stuart and Walker (2017) note the position of the Opimihaw Creek Valley on the northern limit of the summer high pressure ridge may influence the moisture regime of the Valley, resulting in increased moisture conditions here.

### 7.5 Interpretation of $\delta^{13}\text{C}$ Values from Phytoliths

The second objective of this thesis was to obtain stable carbon isotope data to supplement the climate data obtained from phytolith morphological data. A total of 14  $\delta^{13}\text{C}$  values were obtained from 15 samples selected from the six archaeological sites analyzed in this thesis. Ten of the samples were sent to G.G. Hatch Stable Isotope Laboratory at the University of Ottawa for analysis. Additionally, the five radiocarbon samples sent to Beta Analytic (Sec 6.3.2.1.) were also subject to  $\delta^{13}\text{C}$  analysis, as Beta includes this type of analysis with AMS dating. In total, 15  $\delta^{13}\text{C}$  values were submitted, however, one of these samples (FbNp-24-10) did not contain sufficient carbon to yield a  $\delta^{13}\text{C}$  value. The results of the  $\delta^{13}\text{C}$  analysis are summarized in Table 7.1 and Table 7.2 below.

Table 7.1:  $\delta^{13}\text{C}$  results from selected phytolith samples from G.G. Hatch Isotope Laboratory

Sample	G.G. Hatch Lab ID	Depth Below Surface (cm)	%C	$\delta^{13}\text{C}$ Value (‰)
FbNp-1-39	B1718-519-001	10-15	0.17	-27.3
FbNp-17-2	B1718-519-002	85-90	0.24	-30.4
FbNp-17-16	B1718-519-003	20-25	0.13	-27.8
FbNp-22-12	B1718-519-004	55-58	0.16	-27.8
FbNp-22-17	B1718-519-005	40-45	0.22	-25.8
FbNp-24-10	B1718-519-006	17-22	0.11	-27.7
FbNp-25-3	B1718-519-007	45-48	0.13	-26.4
FbNp-25-4	B1718-519-008	40-45	0.24	-27.6
FbNp-25-7	B1718-519-009	15-22	0.12	-25.9
FbNp-25-8	B1718-519-010	12-19	0.23	-28.4

Table 7.2:  $\delta^{13}\text{C}$  results from selected phytolith samples from Beta Analytic

Sample	Beta Sample ID Number	Depth Below Surface (cm)	$\delta^{13}\text{C}$ Value (%)
FbNp-26-7	485183	21-23	-27.8
FbNp-17-2	485184	85-90	-31.5
FbNp-17-16	485185	20-25	-28.6
FbNp-22-20	485186	21-26	-28.8
FbNp-24-10	485187	17-22	Insufficient carbon for analysis

As discussed in Section 5.3, average  $\delta^{13}\text{C}$  values from phytoliths for  $\text{C}_3$  plants range between -34.4% to -25.5% with an average value of -29.2%. Average  $\delta^{13}\text{C}$  values from phytoliths for  $\text{C}_4$  -25.7% to -15.1% with an average value of -21% (Smith & White 2004). The  $\delta^{13}\text{C}$  values from all 14 phytolith samples fell within the expected range of values for  $\text{C}_3$  plants. This suggests that  $\text{C}_3$  plants were the dominant vegetation type in the Opimihaw Creek Valley throughout the late Holocene. The  $\delta^{13}\text{C}$  values obtained here suggest that conditions within the Opimihaw Creek Valley during the late Holocene were not sufficiently warm and dry to result in a shift from  $\text{C}_3$  to  $\text{C}_4$  vegetation. This suggests that during the late Holocene the valley was dominated by a  $\text{C}_3$  grassland or Aspen Parkland environment and the valley was not represented by a Shortgrass prairie environment. This supports the results of the phytolith morphological data, which suggest a dominance of  $\text{C}_3$  grasses within the Opimihaw Creek Valley throughout the 5000+ year record obtained.

It is important to note that the phytolith  $\delta^{13}\text{C}$  values obtained in this research are representative of all phytoliths contained in the sample extracts and are not exclusive to grass short-cell types. The  $\delta^{13}\text{C}$  values represented here likely include deciduous trees and shrubs as well as grass taxa. All tree species, most shrubs, and approximately half of grass species are  $\text{C}_3$ , while the remaining half of the grass species are  $\text{C}_4$  (Sage et al. 1999). The modern vegetation within the Opimihaw Creek Valley includes grasses, shrubs, and tree groves, the relative presence of which are influenced by the topography, moisture availability, and sun exposure (Section 2.5.3). It is not possible for  $\delta^{13}\text{C}$  values to distinguish between grassland and forest vegetation; therefore the  $\delta^{13}\text{C}$  values obtained in this research are assumed to represent deciduous trees and shrubs, as well as grass taxa. It is for this reason that phytolith



morphological analysis pairs well with  $\delta^{13}\text{C}$  values, as phytolith morphological data has the potential to distinguish between these types of vegetation shifts (Fredlund & Tieszen 1994).

### 7.6 Interpretation of Radiocarbon Dates from Phytoliths

The third objective of this thesis was to test the accuracy of radiocarbon dates obtained from phytoliths at Wanuskewin Heritage Park. In light of the issues surrounding radiocarbon dating of phytoliths (see Section 5.2), samples that correlated with previously obtained radiocarbon dates and diagnostic projectile points were selected for radiocarbon analysis (Section 6.3.2.1). These samples were chosen in order to test the accuracy of the radiocarbon dates obtained using the extraction method employed in this research. Table 7.3 compares the radiocarbon dates from phytoliths with the expected radiocarbon ages based on previously obtained bone- and charcoal-derived radiocarbon dates (Smith 2012:36; Stumborg 2016:57; Walker et al. 1986:38, 40). One sample, FbNp-24-10, did not contain sufficient carbon to yield a radiocarbon date (Table 7.3).

Table 7.3: Radiocarbon dates from phytolith samples compared with expected radiocarbon ages.

Sample	Beta Sample ID Number	Depth Below Surface (cm)	Phytolith-derived Conventional Radiocarbon Age (BP)	Established Conventional Radiocarbon Age (BP)	Difference Between Obtained and Expected Dates (years)
FbNp-26-7	485183	21-23	4510 $\pm$ 30 BP	2620 $\pm$ 30/ 2360 $\pm$ 30	1890/ 2150
FbNp-17-2	485184	85-90	7810 $\pm$ 30	4120 $\pm$ 190	3690
FbNp-17-16	485185	20-25	5990 $\pm$ 30	635 $\pm$ 85 to 905 $\pm$ 155	5355 to 5085
FbNp-22-20	485186	21-26	4100 $\pm$ 30 BP	524 $\pm$ 40	3576
FbNp-24-10	485187	17-22	Insufficient carbon for analysis	3460 $\pm$ 45	Insufficient carbon for analysis

As indicated in Table 7.3, the radiocarbon ages obtained from phytoliths are consistently too old by 1890 to 5355 years. The established radiocarbon ages are consistent with projectile point typologies at each site, which attests to the accuracy of the existing bone- and charcoal-derived dates. The established inaccuracy of the phytolith-derived radiocarbon dates is consistent with studies from various locations, including France, Australia, and China, which have produced phytolith-derived radiocarbon dates that are inexplicably older than expected (Section 5.2).

The extraction methodology in this thesis used a 5 minute bleach treatment followed by a 30% H<sub>2</sub>O<sub>2</sub> bath to remove organic matter. While some samples required an additional treatment with HNO<sub>3</sub> to sufficiently oxidize the organic matter (Section 6.2.2), none of these samples were submitted for radiocarbon analysis. It has been suggested that H<sub>2</sub>O<sub>2</sub> may not be sufficient to remove soil organic matter (SOM) attached to phytoliths in order to produce an accurate radiocarbon date in all cases (e.g. Kelly et al. 1991; McClaren & Umlauf 2000). Some researchers suggest a stronger reagent (e.g. HNO<sub>3</sub>, HClO<sub>3</sub>, KOH) may be required to adequately remove SOM bound to phytoliths (Corbineau et al. 2013; Piperno 2006). It is important to note that it is possible for strong acid extractions to be too aggressive, which can damage the phytoliths and degrade the carbon within (Parr & Sullivan 2014; Reyerson et al. 2016).

The extraction protocol used in this thesis was originally set up for phytolith morphological analysis. As knowledge of the potential of phytoliths to provide radiocarbon dates became available, it became evident that WHP represented an excellent opportunity to test the accuracy of phytolith radiocarbon dates as previous radiocarbon dates and relative dates from diagnostic projectile points are available at several sites within the Park. It is not uncommon for extraction methods designed for morphological analysis to be used for radiocarbon analysis as well (see Corbineau et al. 2013:Table 1). This research sought to test if the use of H<sub>2</sub>O<sub>2</sub> as the sole oxidizing agent is sufficient to produce accurate radiocarbon dates from samples at WHP. At a minimum, a 6+ hour bath in H<sub>2</sub>O<sub>2</sub> is recommended to sufficiently remove organic matter from phytoliths (Piperno 2006). The samples submitted for radiocarbon analysis in this research were all subject to a minimum 6 hour bath in H<sub>2</sub>O<sub>2</sub> (Section 6.2.2), which suggested these samples should be sufficiently free of SOM to produce accurate radiocarbon dates. The results of this research suggest this was not the case, as the radiocarbon ages obtained in this thesis are too old by 1890 to 5355 years. This was not surprising as based on the current literature, it appears the most success in obtaining radiocarbon dates from phytoliths is had by researchers who do not use H<sub>2</sub>O<sub>2</sub> as the sole oxidizing agent (Section 5.2).

Consequently, this research supports the hypothesis that phytolith samples processed with H<sub>2</sub>O<sub>2</sub> as the sole oxidizing agent are inappropriate for radiocarbon analysis. The most success obtaining accurate radiocarbon dates from phytoliths has come from work done by Delores Piperno and fellow researchers in the Neotropics (Section 5.2). Commonly, these studies use a combination of HNO<sub>3</sub> and HClO<sub>3</sub> and do not use H<sub>2</sub>O<sub>2</sub> as an oxidizing agent (e.g. Piperno 2006;

Piperno & Stothert 2003; McMichael et al. 2012). This may be an interesting area to investigate as additional phytolith analyses occur at Wanuskewin Heritage Park. A side-by-side comparison of samples using  $H_2O_2$  alone and samples that use a strong oxidizing agent may provide additional information to test if the use of a strong acid is too damaging to pair with a morphological analysis.

### **7.7 Post-Depositional Translocation of Phytoliths at Wanuskewin Heritage Park**

Samples were chosen at random to include phytoliths from a variety of depositional contexts including presumed A horizons, alluvial, and colluvial contexts. This was done in order to test if phytolith concentrations at WHP can be used as an indicator of past landscape stability and soil formation. This also served to test if processes of translocation have an impact on post-depositional movement of phytolith assemblages within the Opimihaw Creek Valley.

The data collected in this thesis suggest that phytolith counts can be used as an indicator of past landscape stability and/or periods of soil formation within the Opimihaw Creek Valley. In this study, samples with very low phytolith yields ( $n < 100$ ) tend to be associated with such processes as aggradation, lateral migration of the streambed, mass movement, and/or slopewash. Further, samples with moderate phytolith yields ( $100 < n < 250$ ) could typically be associated with weakly developed or thin paleosols which may suggest lower vegetation growth resulting in low phytolith counts. Samples that yielded high phytolith counts ( $n \geq 250$ ) were largely associated with longer periods of landscape stability and pedogenesis.

This research also indicates that phytoliths within the Opimihaw Creek Valley are likely not impacted by process of translocation and/or post-depositional movement. Samples from strata that are associated with processes including aggradation, lateral migration of the streambed, mass movement, and/or slopewash tend to have very low phytolith yields. In addition, this research shows that phytoliths tend to occur in moderate counts in thin and weakly developed paleosols. This fits well with data collected elsewhere, which indicates that phytoliths appear in the highest counts in A horizons, while numbers decrease in B horizons, and are even lower in C horizons (Fishkis et al. 2010; Jones et al. 1963; Jones et al. 1964; Stead 2013).

The data collected in this thesis provide evidence to indicate phytoliths at Wanuskewin are not greatly impacted by translocation. The data presented here also provide evidence that suggests high phytolith counts ( $n \geq 250$ ) may be used to indicate long periods of pedogenesis.

Further, it appears moderate counts of phytoliths ( $100 < n < 250$ ) may be used to indicate weakly developed or thin paleosols, while low phytolith yields ( $n < 100$ ) may be used to indicate periods of landscape instability.

## 7.8 Summary

The interpretation of grass short-cell phytolith morphological data and  $\delta^{13}\text{C}$  values from phytoliths produced complementary paleoenvironmental datasets for the WHP. Both datasets suggest that vegetation within the Valley was dominated by  $\text{C}_3$  vegetation throughout the 5000-year record presented here. The grass short-cell phytolith morphological data do not indicate a static climatic history of the valley. Instead the data indicate known climatic events, as recorded elsewhere in Saskatchewan influenced the vegetation within the Opimihaw Valley.

The data collected here suggest Hypsithermal conditions had ameliorated within the Opimihaw Creek Valley prior to  $4860 \pm 30$  BP. The data also indicate the transition to a cooler, moister post-Hypsithermal climate was not linear; the climate trended towards cooler and moister conditions overall but was punctuated by periods of warmth and aridity. A period of increased moisture from 4000-2500 BP may indicate conditions within the valley were more stable than elsewhere in Saskatchewan. Fluctuating moisture and temperature conditions are suggested from 2500-1000 BP, with some data indicating relatively warm moist conditions during the Besant period. The phytolith data suggest the Opimihaw Creek Valley may not have experienced increased aridity during the Medieval Warm Period (1000-700 BP) as is seen elsewhere on the Northern Plains. Conditions resembling the modern climate developed within the Valley around 500–300 BP.

The radiocarbon dates obtained from phytoliths returned dates that were thousands of years older than dates obtained previously from bone and charcoal. This research sought to test if the use of  $\text{H}_2\text{O}_2$  as the sole oxidizing agent is sufficient to produce accurate radiocarbon dates from samples at WHP. Based on the current literature, it appears the use of  $\text{H}_2\text{O}_2$  as an oxidizing agent in the phytolith extraction process may be linked to erroneous radiocarbon dates. The results of the radiocarbon dates obtained in this thesis provide further evidence to support the sole use of  $\text{H}_2\text{O}_2$  as an oxidizing agent should be avoided if one wishes to obtain accurate radiocarbon dates from phytoliths. Future phytolith analysis at WHP represents an opportunity for the comparison of radiocarbon dates from phytolith samples extracted using  $\text{H}_2\text{O}_2$  with samples extracted using a strong acid.

## CHAPTER 8

### SUMMARY AND CONCLUSION

#### 8.1 Summary and Conclusion

The research presented and discussed in this thesis focused on four main objectives:

- 1) To continue to develop a local record of paleoenvironmental change within Wanuskewin Heritage Park through the analysis of phytolith morphological data.
- 2) To obtain  $\delta^{13}\text{C}$  values from phytoliths to supplement the data obtained from grass short-cell phytolith morphological data alone.
- 3) To test the accuracy of radiocarbon dates obtained from phytoliths using the extraction method employed in this research.
- 4) To discuss how the local paleoenvironmental data derived from the phytolith analyses fit within what is known about the Holocene environmental record of the Northern Plains.

The main objective of this thesis was to continue to develop a paleoenvironmental record for Wanuskewin Heritage Park to aid in improving our understanding of how the environment within the park fits within the broader environmental context of the Northern Plains. While archaeological investigations within WHP have led to extensive documentation and discussion of past human lifeways within the Park, a local record of environmental change for WHP is required to aid in the understanding of if, or how, past peoples responded to climate change within the immediate area. Phytolith data obtained from the selected sites within WHP has added to the development of a paleoenvironmental record for the park and has aided in the understanding of how the environment within the park fits within the broader environmental context of the Northern Plains.

The first objective of this research was met through the morphological analysis of phytoliths extracted from 30 samples collected from six archaeological sites. This data suggests  $\text{C}_3$  grasses were dominant within WHP throughout the 5000 year record. While the phytolith data suggest relative stability throughout the Holocene, this does not imply conditions were static. Instead, the data suggest changes within the relative proportions of Pooideae, Chloridoideae,

Stipeae, and Panicoideae fluctuated over time and these fluctuations sometimes align with known paleoclimatic changes recorded elsewhere in Saskatchewan, and sometimes do not.

The second objective of this research was met by obtaining  $\delta^{13}\text{C}$  values from 14 phytolith samples collected from six archaeological sites. The  $\delta^{13}\text{C}$  values from all 14 phytolith samples fell within the expected range of values for  $\text{C}_3$  plants, suggesting that  $\text{C}_3$  plants were the dominant vegetation type in the Opimihaw Creek Valley throughout the late Holocene. These data support the results of the phytolith morphological data which reflects the presence of  $\text{C}_3$  grasses as the dominant grass-type within WHP throughout the available 5000 year record.

The third objective of this research was addressed by obtaining radiocarbon dates from four phytolith samples collected from three archaeological sites from deposits of known age, based on a combination of projectile point typologies and existing radiocarbon dates obtained from faunal specimens. These samples were chosen in order to test the accuracy of the radiocarbon dates obtained from phytoliths using the extraction method employed in this research. A fifth sample from a fourth archaeological site was sent for analysis but did not contain sufficient carbon to yield a radiocarbon result. The four samples that yielded radiocarbon results were 1890 to 5355 years too old. Radiocarbon dates from phytoliths matching expected values from other materials have been recovered in the Neotropics and other areas, however, success outside this geographic region is variable and limited. This is currently an active area of research among those who study phytoliths. It appears the issue may be linked to the use of  $\text{H}_2\text{O}_2$  as an oxidizing agent in the phytolith extraction process. This solvent may not be sufficient to remove “old carbon” potentially sourced from soil organic matter which may adhere to the surface of phytoliths. The use of a strong acid such as  $\text{HNO}_3$  and  $\text{HClO}_3$ , which have been used in successful studies in the Neotropics, may be required to obtain accurate radiocarbon dates from phytoliths. The results of the radiocarbon dates obtained in this thesis provide further evidence to support the use of  $\text{H}_2\text{O}_2$  as the sole oxidizing agent should be avoided if one wishes to obtain accurate radiocarbon dates from phytoliths. Future phytolith analysis at WHP represents an opportunity for the comparison of radiocarbon dates from phytolith samples extracted using  $\text{H}_2\text{O}_2$  with samples extracted using a stronger reagent.

The fourth objective of this research was addressed by correlating the paleoenvironmental data obtained from the 30 phytolith samples along with the  $\delta^{13}\text{C}$  values from 14 of these samples with the broader paleoenvironmental context of the Northern Plains. Based

on their association with existing radiocarbon dates, the oldest samples analyzed as part of the current research date to ca. 5000-4000 BP, which correlates with the end of the Hypsithermal on the Northern Plains. Taken together, samples that date to this period suggest that the decline of the Hypsithermal was not linear, that the climate trended towards cooler and moister conditions overall but punctuated by periods of warmth and aridity. These data fit with the climate data from elsewhere in Saskatchewan which suggests that peak Hypsithermal warming occurred between 8000-6000 BP, followed by a trend toward cooler, moister temperatures punctuated by periods of warmth and aridity.

The data suggest the following period (4000-1000 BP) was also characterized by fluctuating temperature and moisture conditions, however, overall conditions were cooler and moister than the previous period, though still warmer than modern conditions. Data from elsewhere in Saskatchewan also suggest fluctuating conditions during this period. The phytolith morphological data suggest increased temperatures that correlate with the timing of the Medieval Warm Period (1000-700 BP). The data also indicate increased rainfall during the summer months. This is of particular interest, as elsewhere in Saskatchewan the Medieval Warm Period is characterized by increased aridity. The data from Wanuskewin Heritage Park suggests that MWP conditions on the Northern Plains may be more variable than previously thought. The youngest samples in this analysis date to  $<380 \pm 70$  BP. These samples suggest that climate conditions within WHP at this time were similar to modern conditions.

The results of this analysis provide a paleoenvironmental record for Dog Child (FbNp-24), Thundercloud (FbNp-25), Wolf Willow (FbNp-26), Amisk (FbNp-17), Cut Arm (FbNp-22), and Tipperary Creek (FbNp-1) sites based on phytolith morphological data and  $\delta^{13}\text{C}$  values from phytoliths. The results of the radiocarbon dates obtained from phytoliths was unsuccessful in obtaining accurate dates, suggesting the extraction method used in this thesis is not suitable for the recovery of accurate radiocarbon dates from phytoliths. This has contributed to the ongoing research which suggests the use of  $\text{H}_2\text{O}_2$  as the sole oxidizing agent may be insufficient for the extraction of phytoliths for radiocarbon analysis. This may be an interesting area to investigate at Wanuskewin Heritage Park. Such research has the potential to provide additional information to test if the use of a strong acid is too damaging to pair with a morphological analysis.

The research presented here adds to the existing body of paleoclimate data for WHP and has provided a paleoenvironmental context for the human occupation of Dog Child (FbNp-24),

Thundercloud (FbNp-25), Wolf Willow (FbNp-26), Amisk (FbNp-17), Cut Arm (FbNp-22), and Tipperary Creek (FbNp-1). The combination of the data collected from these sites has helped to place WHP within the broader paleoenvironmental context of the Northern Plains and has contributed to the knowledge of the paleoenvironment of this region. The data presented here have further supported the idea that WHP represents an excellent location for the analysis of phytolith morphological and  $\delta^{13}\text{C}$  data.

## **8.2 Areas for Future Research**

The research presented here is an important early step towards a detailed, large scale paleoenvironmental reconstruction for WHP. Recommendations for further research include the development of a complete phytolith record for each of the six sites presented here. This would include the analysis of samples from every stratum present at each of the six sites. This would help to create a more detailed picture of the paleoenvironmental record at each of these sites. To expand on this research, and to develop a clearer picture of the paleoenvironmental record of the valley as a whole, a complete analysis of the phytolith morphological and  $\delta^{13}\text{C}$  record from all archaeological sites within the Park is recommended. Further, the success of this method within the Opimihaw Creek Valley suggests this type of analysis should be successful in other tributary valleys along the South Saskatchewan River. The repeated use of this method in other, similar areas throughout the Northern Plains would help to build a more detailed record of the paleoenvironmental conditions of this region within the broader Northern Plains environment.

The research presented here focused on the morphological analysis of phytoliths within the grass family. Grasses are a major contributor to the vegetation profile of the area, however, they are not the sole plant taxa present within the region. Phytoliths are produced by many other plant types, including sedges, trees, and cacti, several species of which are found within WHP today. A morphological analysis of grass species alone is limiting in terms of paleoenvironmental interpretations, as it can only speak of a subset of the past vegetation. The analysis of other phytolith types found within samples at WHP would be beneficial in understanding how plants outside the grass family reacted to climatic changes throughout the Holocene. The combination of the phytolith data presented here with data from other proxy environmental indicators (e.g. pollen data, macrofloral analysis) will provide a more detailed



view of past environmental conditions within the Park. Plans for such an integrated analysis exist, as the development of a detailed pollen record for the Park is currently underway.

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## APPENDIX A

### TOTAL SHORT CELL PHYTOLITH COUNTS

This appendix presents the results of the total short-cell phytolith raw counts and the relative frequencies of the short-cell phytoliths from Dog Child (FbNp-24), Thundercloud (FbNp-25), Wolf Willow (FbNp-26), Amisk (FbNp-17), Cut Arm (FbNp-22), and Tipperary Creek (FbNp-1).

Table A.1: Total short-cell phytolith counts from samples at FbNp-24.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
10	17-22	41	72	35	53	13	15	15	6	250
8	34-37	0	15	9	30	0	0	0	0	54
7	44-47	0	45	0	60	3	18	0	0	126
4	65-70	6	9	6	6	6	0	0	0	33
2	78-82	0	0	3	0	0	0	0	0	3

Table A.2: Total short-cell phytolith counts from samples at FbNp-25.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
8	12-19	8	129	91	15	7	0	0	0	250
7	15-22	7	147	85	1	10	0	0	0	250
4	40-45	7	109	80	0	52	0	0	2	250
3	45-48	22	61	149	0	18	0	0	0	250
2	58-63	43	61	46	8	92	0	0	0	250

Table A.3: Total short-cell phytolith counts from samples at FbNp-26.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
9	2-5	36	99	5	49	45	11	5	0	250
7	21-23	53	83	17	21	27	37	12	0	250
5	34-36	70	79	19	13	13	0	0	0	194
2	64-66	99	72	27	12	36	0	0	4	250
1	72-76	101	28	49	27	45	0	0	0	2

Table A.4: Total short-cell phytolith counts from samples at FbNp-17.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
16	20-25	28	60	19	91	21	19	12	0	250
12	40-47	30	15	3	45	0	3	3	0	99
10	48-50	21	45	0	63	18	21	15	0	183
6	55-60	0	6	0	24	18	0	0	0	48
2	85-90	26	47	11	89	22	23	32	0	250

Table A.5: Total short-cell phytolith counts from samples at FbNp-22.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
20	21-26	28	84	0	70	19	19	29	1	250
17	40-45	11	53	17	71	11	47	40	0	250
12	55-58	7	144	15	41	5	15	23	0	250
7	85-89	6	39	12	81	0	15	9	0	162
2	113-117	9	54	24	39	0	0	3	0	129

Table A.6: Total short-cell phytolith counts from samples at FbNp-1.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total Raw Count
39	10-15	27	78	29	38	7	50	21	0	250
31	63-65	6	12	6	0	0	0	0	0	24
25	85-90	34	88	17	68	6	17	20	0	250
6	131-137	24	18	6	27	3	6	6	0	90
23	190-192	11	4	5	9	1	0	0	0	30

Table A.7: Relative frequency of short-cell morphotypes from Samples at FbNp-24.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
10	17-22	16.4	28.8	14.0	21.2	5.2	6.0	6.0	2.4	100.0
8	34-37	0.0	27.8	16.7	55.6	0.0	0.0	0.0	0.0	100.0
7	44-47	0.0	35.7	0.0	47.6	2.4	14.3	0.0	0.0	100.0
4	65-70	18.2	27.3	18.2	18.2	18.2	0.0	0.0	0.0	100.0
2	78-82	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	100.0

Table A.8: Relative frequency of short-cell morphotypes from Samples at FbNp-25.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
8	12-19	3.2	51.6	36.4	6.0	2.8	0.0	0.0	0.0	100.0
7	15-22	2.8	58.8	34.0	0.4	4.0	0.0	0.0	0.0	100.0
4	40-45	2.8	43.6	32.0	0.0	20.8	0.0	0.0	0.8	100.0
3	45-48	8.8	24.4	59.6	0.0	7.2	0.0	0.0	0.0	100.0
2	58-63	17.2	24.4	18.4	3.2	36.8	0.0	0.0	0.0	100.0

Table A.9: Relative frequency of short-cell morphotypes from Samples at FbNp-26.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
9	2-5	14.4	39.6	2.0	19.6	18.0	4.4	2.0	0.0	100.0
7	21-23	21.2	33.2	6.8	8.4	10.8	14.8	4.8	0.0	100.0
5	34-36	36.1	40.7	9.8	6.7	6.7	0.0	0.0	0.0	100.0
2	64-66	39.6	28.8	10.8	4.8	14.4	0.0	0.0	1.6	100.0
1	72-76	40.4	11.2	19.6	10.8	18.0	0.0	0.0	0.0	100.0

Table A.10: Relative frequency of short-cell morphotypes from Samples at FbNp-17.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
16	20-25	11.2	24.0	7.6	36.4	8.4	7.6	4.8	0.0	100.0
12	40-47	30.3	15.2	3.0	45.5	0.0	3.0	3.0	0.0	100.0
10	48-50	11.5	24.6	0.0	34.4	9.8	11.5	8.2	0.0	100.0
6	55-60	0.0	12.5	0.0	50.0	37.5	0.0	0.0	0.0	100.0
2	85-90	10.4	18.8	4.4	35.6	8.8	9.2	12.8	0.0	100.0

Table A.11: Relative frequency of short-cell morphotypes from Samples at FbNp-22.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
20	21-26	11.2	33.6	0.0	28.0	7.6	7.6	11.6	0.4	100.0
17	40-45	4.4	21.2	6.8	28.4	4.4	18.8	16.0	0.0	100.0
12	55-58	2.8	57.6	6.0	16.4	2.0	6.0	9.2	0.0	100.0
7	85-89	3.7	24.1	7.4	50.0	0.0	9.3	5.6	0.0	100.0
2	113-117	7.0	41.9	18.6	30.2	0.0	0.0	2.3	0.0	100.0

Table A.12: Relative frequency of short-cell morphotypes from Samples at FbNp-1.

		Pooideae				Chloridoideae	<i>Stipa</i>	Panicoideae		
Sample	Depth Below Surface (cm)	Keeled	Conical	Pyramidal	Crenate	Saddle	<i>Stipa</i> -type	Lobate	Cross	Total %
39	21-26	10.8	31.2	11.6	15.2	2.8	20.0	8.4	0.0	100.0
31	40-45	25.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	100.0
25	55-58	13.6	35.2	6.8	27.2	2.4	6.8	8.0	0.0	100.0
2	85-89	26.7	20.0	6.7	30.0	3.3	6.7	6.7	0.0	100.0
23	113-117	36.7	13.3	16.7	30.0	3.3	0.0	0.0	0.0	100.0

APPENDIX B  
GRASS SHORT-CELL PHYTOLITH PHOTOGRAPHS

This appendix presents the grass short-cell phytolith photographs taken during morphological analysis of samples analyzed in this thesis.

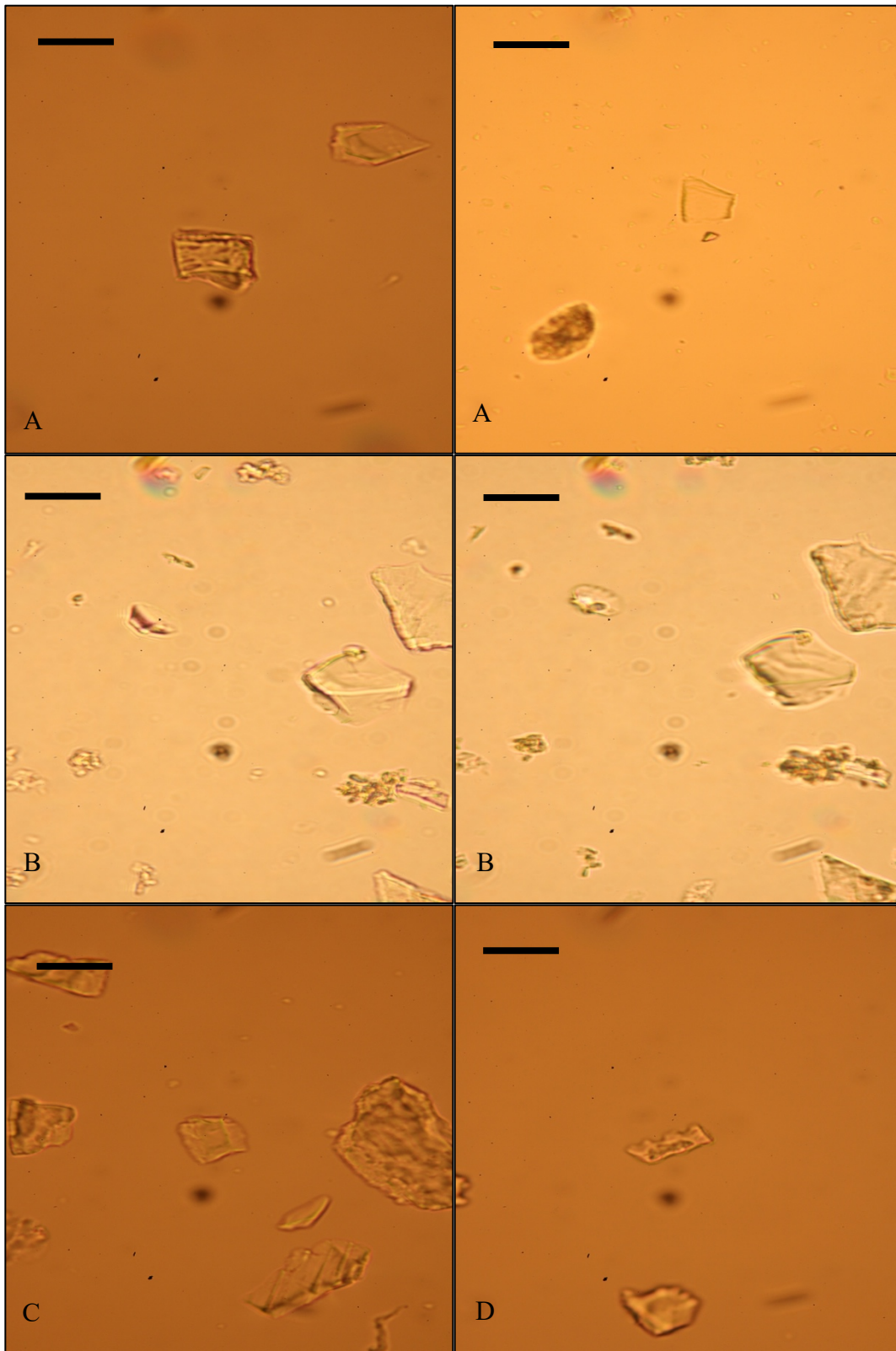


Figure B.1: Examples of phytolith morphotypes recorded. A= Keeled; B= Conical; C= Pyramidal; D= Crenate. Bar scales are 20 microns.



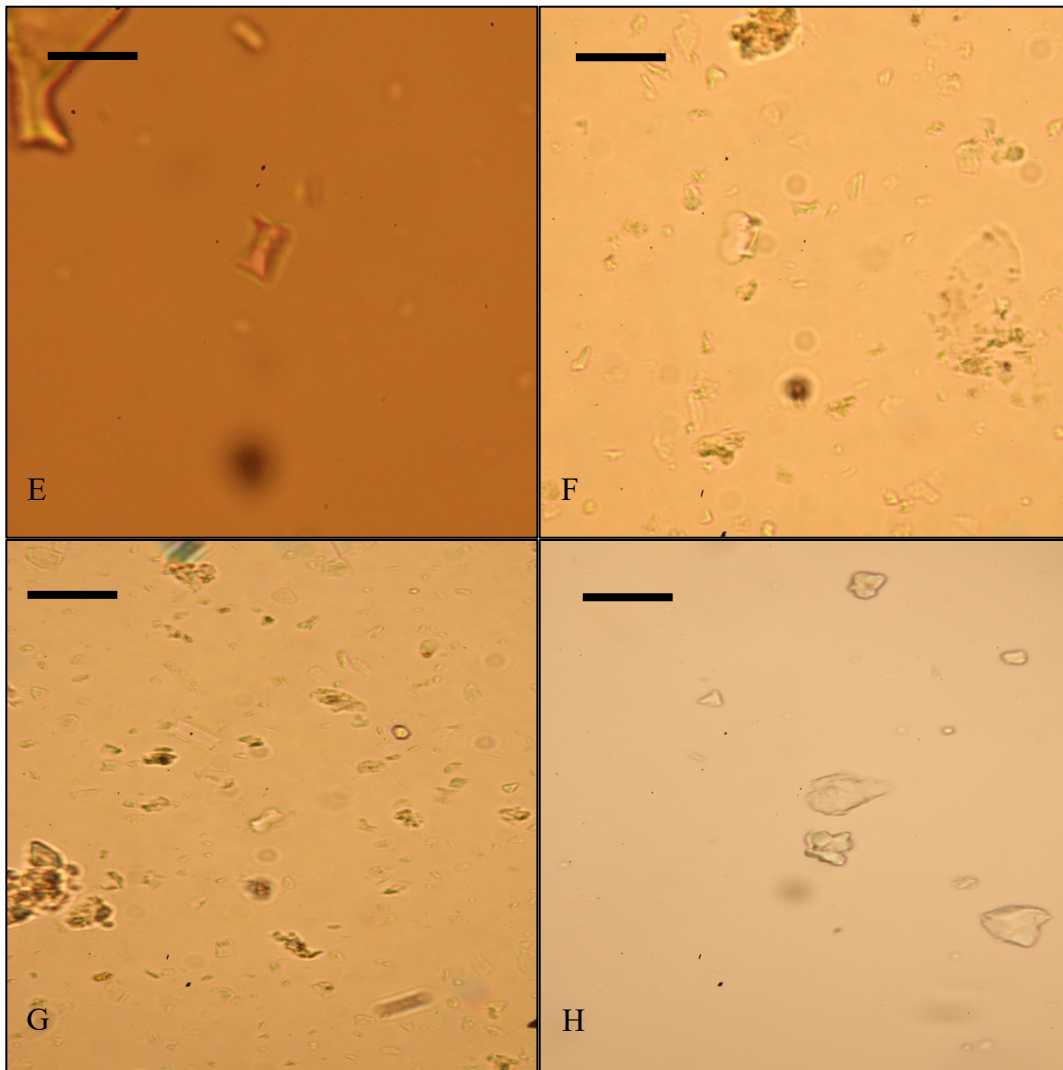


Figure B.2: Examples of phytolith morphotypes recorded. E= Saddle; F= *Stipa*-type; G= Lobate; H= Cross. Bar scales are 20 microns